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FEBRUARY 1966
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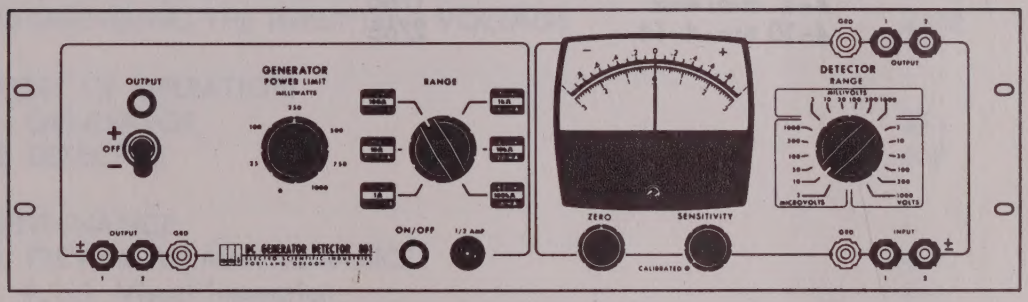
MODEL

801

Instruction Manual

DC GENERATOR DETECTOR



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ACKNOWLEDGMENTS

We wish to thank Hewlett-Packard Company for information concerning theory of operation, maintenance, schematic diagrams, and calibration and adjustment procedures for the detector. In particular, paragraphs 3.2, 4.2, 4.3, and 4.4 were adapted from the instruction manual for the Hewlett-Packard Model 419A DC Null Detector by permission of Hewlett-Packard.

SECTION I
INTRODUCTION

1.1 DESCRIPTION

The ESI Model 801 is a dc generator and null detector (microvoltmeter). The instrument features double-chassis construction, or guarding, to greatly reduce stray leakage paths to ground. Leakage from the high generator terminal and from the high detector terminals to ground has been virtually eliminated. Insulation of the other terminals is kept to 10^{11} ohms or greater.

The output of the generator is continuously variable and is limited to a maximum of one watt into a matched load. A front panel control selects six output impedance ranges to match loads from 1 ohm to 100 kilohms.

An active circuit line regulator reduces the effect of line transients by a factor of more than ten. Unique guarded relays that control generator power allow remote operation of the generator. In this way, an operator can control the generator with a foot switch or the instrument can be operated by automatic equipment. The generator output terminals are short-circuited when the generator is turned off, which inhibits transient pulses at the instant of turn-on.

The detector features a very sensitive modulator-type dc amplifier. Trouble caused by stray ac pickup from the device under test is greatly reduced by a rejection filter. The modulator operates above the ac line frequency, thus further reducing the ac pickup.

The double-chassis construction and complete integrity of guarding allow either the detector or the generator to be floated more than 600 volts above ground.

The unique design features of the Model 801 make it suitable to a number of applications:

1. Very high resistance bridge measurements can be made with superior accuracy because of the special guarding and shielding features, and because of line transient reduction.

2. Very low resistance bridge measurements can also be made with high accuracy because of the detector sensitivity and the provision for matching the generator to the load.

3. The same features apply to make the 801 an ideal generator-detector combination for calibrating precision voltage dividers. A detailed description of this application may be found in ESI's "Design Ideas", volume 1, number 1. See also Section 2.4 of this Manual.

4. The 801 can be used directly to measure extremely low conductance (high resistance). See Section 2.7.

5. The 801 generator can be used separately wherever a variable, guarded, and power-limited dc supply is needed.

6. The 801 detector can be used separately as a voltmeter or microvoltmeter with ranges up to 1,000 volts.

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6. The 801 detector can be used separately as a voltmeter or microvoltmeter with ranges up to 1,000 volts.

1.2 SPECIFICATIONS

1.2.1 Generator

Range: 6 ranges, continuously variable, 0 to 600V. Power limited to 1 watt.

Regulation: Active-circuit line regulator reduces effect of line transients by a factor of more than ten.

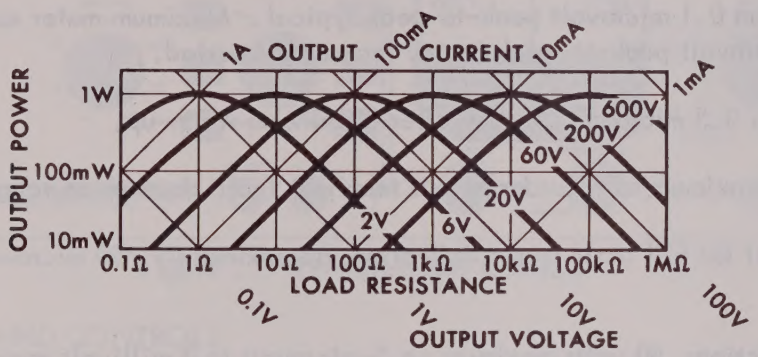

Figure 1.1 Maximum Output of 801 Generator

Insulation Resistance: Terminal 1 greater than 10^{14} ohms;
Terminal 2 greater than 10^{11} ohms;

Output Resistance:

OPEN CIRCUIT VOLTAGE (VOLTS)	2	6	20	60	200	600
SHORT CIRCUIT CURRENT (mA)	2000	600	200	60	20	6
OUTPUT RESISTANCE (OHMS)	1	10	100	1k	10k	100k

1.2.2 Detector

Ranges: Calibrated ±3 microvolts to ±1000 volts dc end scale in 18 zero-center ranges, sensitivity (uncalibrated) can be increased to about 0.75 microvolt end scale.

Accuracy: ±5 percent of end scale, ±0.1 microvolt.

Limits of Zero Control: ±15 microvolts.

Input Resistance: 3-microvolt to 3-millivolt ranges: 100 kilohms.
10-millivolt to 30-millivolt ranges: 1 megohm.
100-millivolt to 300-millivolt ranges: 10 megohms.
1-volt to 1000-volt ranges: 100 megohms.

Response Time: 95 percent of final reading within 4 sec on the 3-microvolt range. 95 percent of final readings within 1.5 sec on the 10-microvolt to 1000-volt ranges.

Superimposed AC Rejection: With frequencies of 60 Hz (cps) or higher (except modulator frequency: 160 to 170 Hz), ac voltages that are 80 dB greater than the end scale will affect the reading less than 2 percent. (AC voltage must be limited to 300 volts rms.)

Noise: Less than 0.1 microvolt peak-to-peak typical. Maximum meter excursion will be 0.2 microvolt peak-to-peak in any ten-second period.

Drift: Less than 0.5 microvolt per day after 30 minutes warm-up.

Gain: 110 dB maximum at recorder output terminals (gain depends on range).

Output: ±1 volt for full scale meter deflection; approximately 750 microamperes maximum.

Overload Protection: 50 volts maximum on 3-microvolt to 3 millivolt ranges; 500 volts maximum on 10-millivolt to 300-millivolt ranges; 1200 volts maximum on 1-volt range and above. Regardless of voltage limitations, the full output of the generator (approximately 600 volts) cannot damage the detector, even on the most sensitive range.

Overload Recovery Time: Meter indicates within 4 seconds for a 10^6 overload with input shorted; less than 15 seconds with input open.

Input Isolation: 10^{11} ohms shunted by 250 picofarads. May be operated more than 600 volts dc or 350 volts ac (rms) above ground.

1.2.3 | Physical

Height:	5 1/4 inches	(13.3 cm)
Length:	19 inches	(48.25 cm)
Depth:	11 inches	(25.7 cm)
Weight:	21 pounds	(9.5 kg)

Power requirements: 117 or 230 volts selected by internal switch, 50 to 400 Hz (cps), 15 watts.

SECTION II

OPERATING INSTRUCTIONS

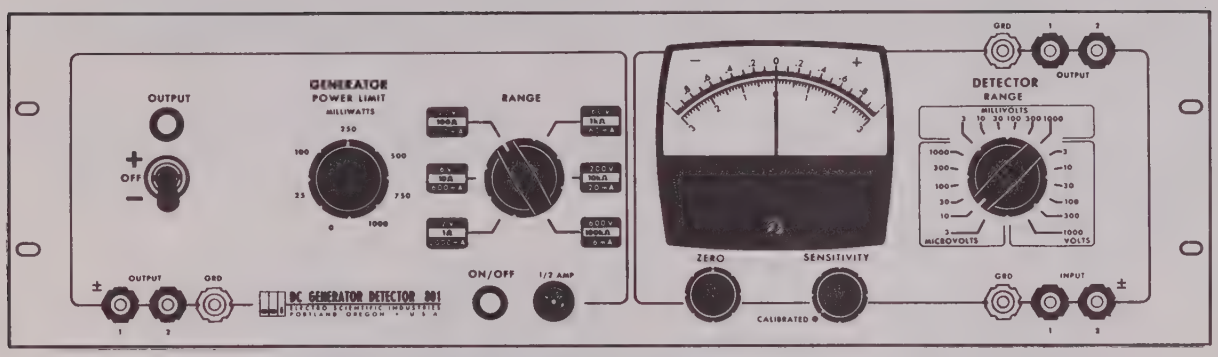

Figure 2.1 Terminals and Controls

2.1 TERMINALS AND CONTROLS

Generator OUTPUT Terminals: The lower left-hand terminals are for connecting the generator to an external circuit.

Detector INPUT Terminals: The lower right-hand terminals are for connecting the detector to an external circuit.

Detector OUTPUT Terminals: The upper right-hand terminals are provided so an external meter or recorder may be conveniently connected to the detector.

Detector ZERO Control: Adjusts the detector zero.

Detector RANGE Selector: Selects the sensitivity range of the detector.

Detector SENSITIVITY Control: Continuously varies the detector sensitivity from a minimum at the CALIBRATED position to a maximum of about four times the end-scale sensitivity indicated by the RANGE selector.

Generator POWER LIMIT Control: Varies the power limit level of the generator from 0 to 1 watt maximum.

Generator RANGE Selector: Selects the generator limiting resistor, the maximum (open circuit) voltage, and maximum (short circuit) current.

Generator OUTPUT Switch: Connects the generator output of the selected polarity to the OUTPUT terminals.

ON/OFF Switch: Controls line power to both generator and detector.

2.2 BASIC OPERATING PROCEDURE

This section describes the basic procedure for using the Model 801 to test or adjust any three-terminal or four-terminal resistive circuit by applying the generator output to one pair of terminals and observing the resulting signal at another pair of terminals with the detector. The procedure is applicable both to null balance applications, such as bridge balancing and voltage divider calibration, and to meter deflection applications, such as ohmmeter, attenuator and unbalanced bridge measurement.

Various specific applications are discussed in the sections of the manual following this one. The basic operating procedure for all of these applications is as follows:

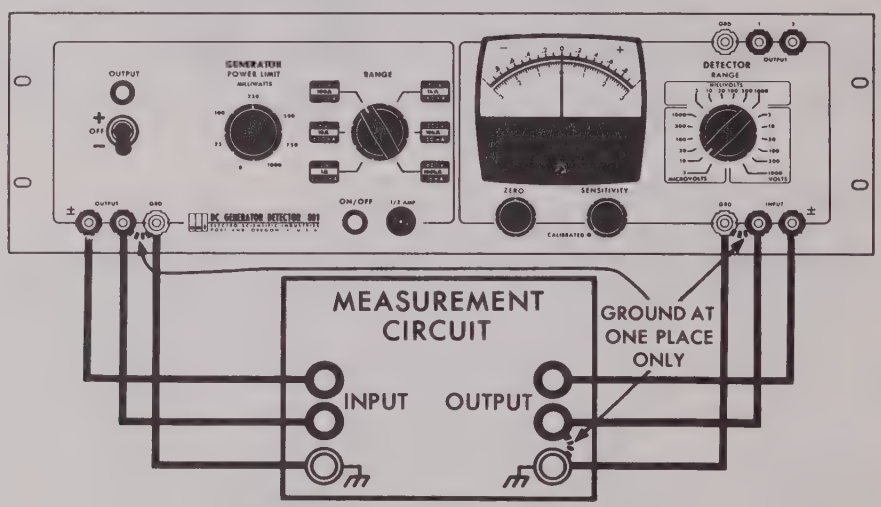

Figure 2.2 Basic Operating Procedure

1. Be sure the generator OUTPUT switch is off, then turn the ON/OFF switch on and allow time for warmup.

2. Connect the measurement circuit to the generator OUTPUT and detector INPUT terminals as shown in Figure 2.2.

   The measurement circuit should be grounded at one point only, so that ground loop currents between chassis cannot flow through these leads.

3. Set the detector SENSITIVITY control at CALIBRATED.

   This adjusts full scale indication to the range setting.

4. Set the detector RANGE switch at 3 microvolts and adjust the ZERO control for meter zero.

   Always adjust zero with detector input connected to the measurement circuit - not open or short circuited - in order to cancel effects causing zero shift with change in source resistance.

5. Change the detector RANGE switch to a range higher than the voltage expected when the generator is first turned on.	This will avoid meter recovery delays caused by input signals greater than full scale.
6. Set the generator POWER LIMIT control to a value which will not cause resistance changes due to heating.	A power setting lower than the lowest-rated resistor in the measurement circuit is always safe.
7. Set the generator RANGE control as desired.	At a setting most nearly equal to the input resistance of the measurement circuit, the generator output will be a maximum, and will usually be approximately equal to the generator power setting.
8. Turn on the generator by setting the OUTPUT switch as desired; the marking indicates the polarity of OUTPUT terminal 1.	The detector polarity is fixed, the direction of the meter deflection corresponding to the polarity of INPUT terminal 2.
9. Adjust the generator POWER LIMIT and RANGE controls as required. For maximum power find the generator RANGE setting giving maximum detector deflection. To reduce the power below the generator POWER LIMIT setting, use generator RANGE settings away from the maximum setting - both voltage and current will be reduced as a result of resistance mismatch in either direction.	For further reduction of power, connect either a low-value shunt resistor across the generator OUTPUT terminals 1 and 2 or a high-value series resistor in the OUTPUT 1 lead, and use a generator RANGE setting far away from the value of the shunt or series resistor.
10. Change the detector RANGE setting as required for detector sensitivity. Use the SENSITIVITY control to increase the detector sensitivity above the calibrated detector RANGE setting.	Turn off the generator OUTPUT switch and recheck detector ZERO adjustment each time detector RANGE is changed toward higher sensitivity.
11. Take as the final meter reading the change in reading with generator on and generator off (or half the change with generator polarity reversal), to eliminate the effect of imperfect zero adjustment.	Take readings after switching transients have disappeared (normally within one second after turning generator on or off). For maximum sensitivity in null balance applications, generator power can often be increased for final adjustment if generator OUTPUT switch is left on only a few seconds at a time to minimize resistor heating.

2.3 USING THE 801 FOR BRIDGE MEASUREMENTS

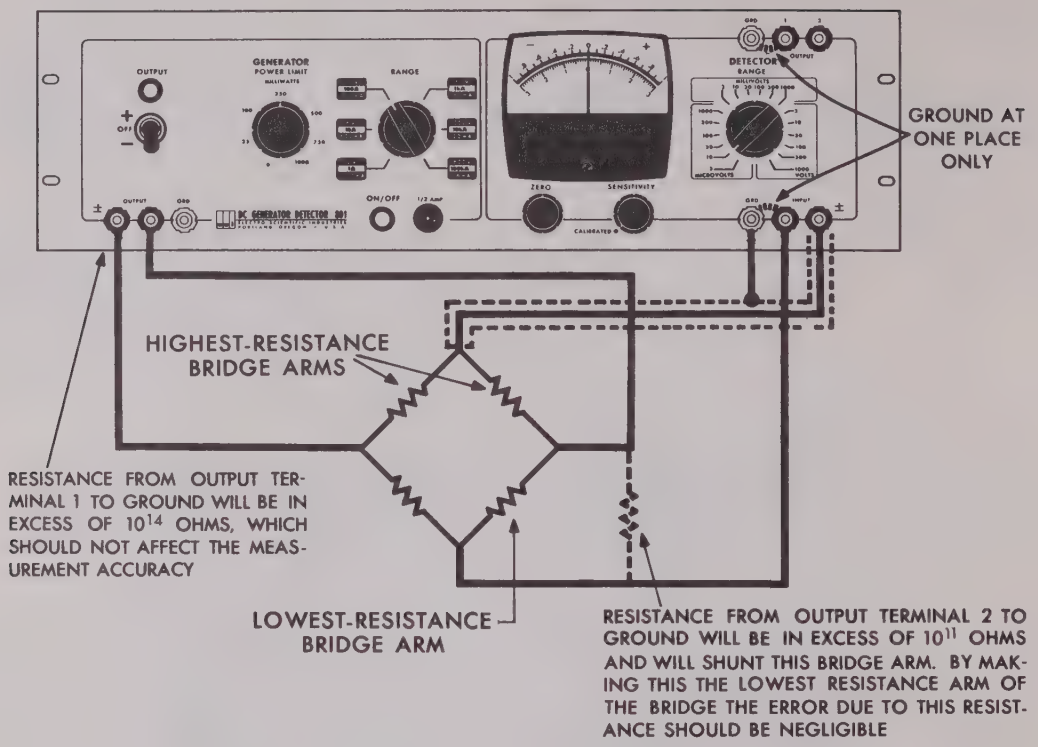
GROUND AT ONE PLACE ONLY
HIGHEST-RESISTANCE BRIDGE ARMS
RESISTANCE FROM OUTPUT TERMINAL 1 TO GROUND WILL BE IN EXCESS OF 10^{14} OHMS, WHICH SHOULD NOT AFFECT THE MEASUREMENT ACCURACY
LOWEST-RESISTANCE BRIDGE ARM
RESISTANCE FROM OUTPUT TERMINAL 2 TO GROUND WILL BE IN EXCESS OF 10^{11} OHMS AND WILL SHUNT THIS BRIDGE ARM. BY MAKING THIS THE LOWEST RESISTANCE ARM OF THE BRIDGE THE ERROR DUE TO THIS RESISTANCE SHOULD BE NEGLIGIBLE

Figure 2.3 Bridge Measurement Connection

Connect the bridge to the generator OUTPUT and detector INPUT terminals as shown in Figure 2.3, then balance bridge following basic operating procedure of Section 2.2.

2.4 USING THE 801 FOR VOLTAGE DIVIDER CALIBRATION

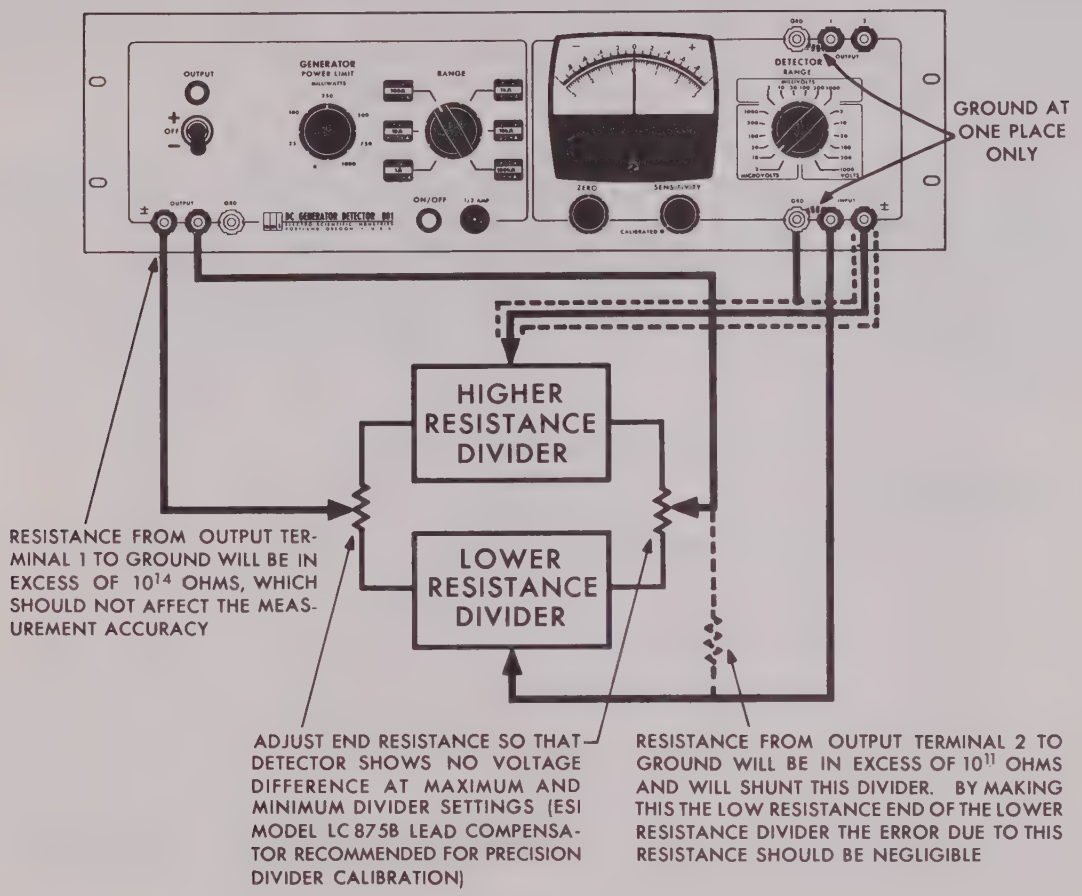
GROUND AT ONE PLACE ONLY
HIGHER RESISTANCE DIVIDER
LOWER RESISTANCE DIVIDER
RESISTANCE FROM OUTPUT TERMINAL 1 TO GROUND WILL BE IN EXCESS OF 10^{14} OHMS, WHICH SHOULD NOT AFFECT THE MEASUREMENT ACCURACY
ADJUST END RESISTANCE SO THAT DETECTOR SHOWS NO VOLTAGE DIFFERENCE AT MAXIMUM AND MINIMUM DIVIDER SETTINGS (ESI MODEL LC 875B LEAD COMPENSATOR RECOMMENDED FOR PRECISION DIVIDER CALIBRATION)
RESISTANCE FROM OUTPUT TERMINAL 2 TO GROUND WILL BE IN EXCESS OF 10^{11} OHMS AND WILL SHUNT THIS DIVIDER. BY MAKING THIS THE LOW RESISTANCE END OF THE LOWER RESISTANCE DIVIDER THE ERROR DUE TO THIS RESISTANCE SHOULD BE NEGLIGIBLE

Figure 2.4 Voltage Divider Connection

Connect the pair of dividers or attenuators to the generator OUTPUT and detector INPUT terminals as shown in Figure 2.4, then adjust to find pairs of settings giving detector null indications, following the basic operating procedure of Section 2.2.

2.5 USING THE 801 FOR TOLERANCE CHECKING BY DEFLECTION

Where repeated measurements are to be made to detect small variations of a resistive circuit from a standard value, meter deflection methods can save a great deal of time. Such applications are the checking of batches of resistors for accuracy, the calibration of voltage dividers where an exact null balance is not convenient, or the testing of resistors or resistive networks for changes with temperature or other ambient conditions.

For such deflection measurements, use the appropriate bridge or divider connection as discussed in Sections 2.3 and 2.4. Follow the basic procedure of Section 2.2 in the initial adjustment of the circuit. At steps 9 and 10, adjust the generator POWER LIMIT or the detector RANGE and SENSITIVITY controls so that a small change in the bridge or divider setting produces a conveniently related number of divisions of meter change. Now adjust the bridge or standard divider for a meter null at the standard value and read changes from this value in terms of meter deflection.

2.6 USING THE 801 AS AN ULTRA-LOW RESISTANCE OHMMETER

To measure the approximate value of a very low resistance, such as a switch or relay contact or a piece of wire, use the circuit shown in Figure 2.5.

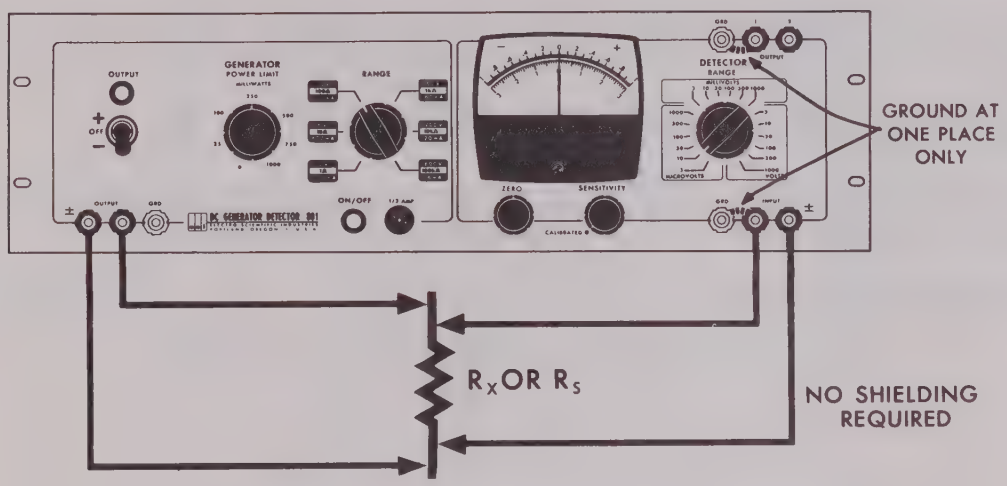

Figure 2.5 Low Resistance Measurement

Follow the basic procedure of Section 2.2 with the following additions:

For ±20 percent accuracy:

1. Before connecting the unknown resistance, connect the detector INPUT leads directly to the generator OUTPUT leads.

2. Set the generator RANGE resistance to a value at least 10 times the value of the unknown resistor.

3. Adjust generator POWER LIMIT so that the voltage reading is an exact power of 10. Call this voltage reading E_G.

4. Connect the unknown resistor R_x in the circuit of Figure 2.5.

5. Leaving generator RANGE and POWER settings alone, but changing detector RANGE as required, measure the voltage. (Be sure that SENSITIVITY control is set to CALIBRATED.) Call this voltage reading E_x.

6. Calculate the unknown resistance value from the formula:

$$\frac{R_x}{E_x} = \frac{\text{Generator RANGE Resistance Setting}}{E_G}$$

For ±5 percent accuracy:

1. Connect a known standard resistor, having a value R_s not greater than 1000 ohms, in the circuit of Figure 2.5.

2. Set the generator RANGE to a value at least 100 times the value of the standard resistor.

3. Adjust generator POWER LIMIT so that the voltage reading is conveniently related to the standard resistance value. Call this voltage reading E_s.

4. Remove the standard resistor and connect the unknown resistor R_x.

5. Leaving generator RANGE and POWER LIMIT settings alone, but changing detector RANGE as required, measure the voltage. Call this voltage reading E_x.

6. Calculate the unknown resistance value from the formula:

$$\frac{R_x}{E_x} = \frac{R_s}{E_s}$$

2.7 USING THE 801 AS AN ULTRA-HIGH RESISTANCE OHMMETER

To measure the approximate value of a very high resistance, such as the leakage in an insulator, use the circuit shown in Figure 2.6.

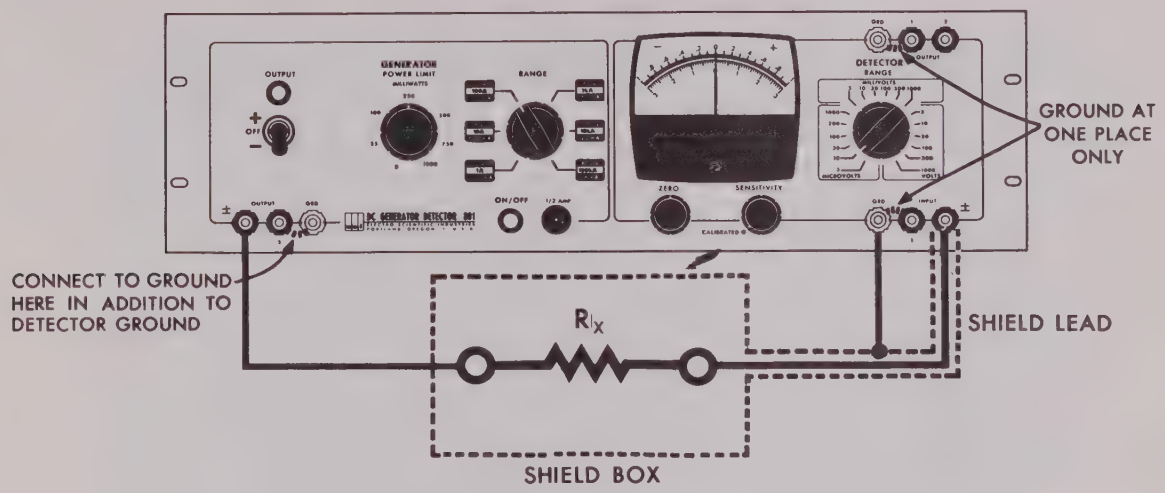

Figure 2.6 High-Resistance Measurement

Follow the basic procedure of Section 2.2 with the following additions:

1. Before connecting the unknown resistance, connect the detector INPUT 2 lead to the generator OUTPUT 1 lead (or connect a short circuit across the unknown resistance).

2. Set generator RANGE to 100 kilohms.

3. Set generator OUTPUT switch either to + or - position and adjust POWER LIMIT control for a detector reading of 500 volts. (Other voltages may be used, but the conversion chart, Figure 2.7, is intended for use with a 500-volt setting.)

4. Connect the unknown resistance R_x in the circuit of Figure 2.6.

5. Leaving the generator RANGE and POWER LIMIT settings alone, but changing detector RANGE as required, measure the voltage. Call this voltage reading E_x.

6. Use the conversion chart, Figure 2.7, to convert the voltage reading to the resistance. (If a voltage other than 500 volts was used in Step 3, use the following conversion formula:

$$R_x = \frac{E_g R_d}{E_x} - R_d$$

where R_x is the unknown resistance,
E_g is the generator voltage,

R_d is the detector resistance, which depends on the RANGE setting:

3 MICROVOLTS to 3 MILLIVOLTS; 100 kilohms
10 MILLIVOLTS to 30 MILLIVOLTS; 1 megohm
100 MILLIVOLTS to 300 MILLIVOLTS; 10 megohms
1000 MILLIVOLTS to 1000 VOLTS; 100 megohms.)

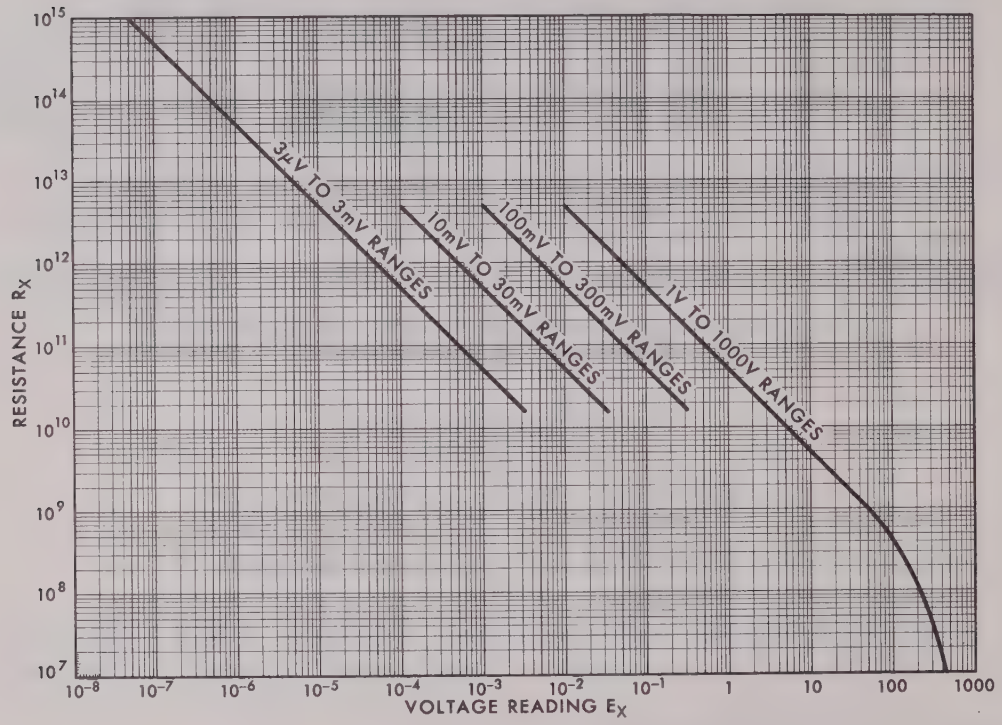

Figure 2.7 Voltage to Resistance Conversion Chart

2.8 USING THE 801 AS A VOLTMETER

To use the Model 801 detector as a voltmeter, connect the voltage to be measured to the detector INPUT terminals, set the SENSITIVITY control to CALIBRATED, and set the RANGE selector to the appropriate voltage range. If there is any doubt about the voltage, use a higher range first and then decrease it.

The voltage (times the range factor) is indicated on the meter. The polarity marked on the meter is the polarity of the voltage connected to INPUT terminal 2.

2.9 REMOTE GENERATOR OPERATION

The generator output is controlled by two unique guarded relays that are controlled either by the OUTPUT switch or by remote switches. A terminal board in the back of the instrument is supplied to connect remote switches such as foot-operated switches or automatic sequencing equipment.

In order to apply a positive voltage to OUTPUT terminal 1, a remote switch must be connected to short-circuit the + and the COM terminals in the rear of the instrument. Similarly, to apply a negative voltage, a remote switch must short-circuit the - and the COM terminals.

There is no necessity to prevent simultaneous connections; if both terminals in the rear are short-circuited to COM or if, for example, the - terminal is connected to the COM terminal and the OUTPUT switch is set to + , no damage will be done since the relays will disconnect the generator when they are both energized.

Figure 2.8 is a simplified schematic of the generator control circuits.

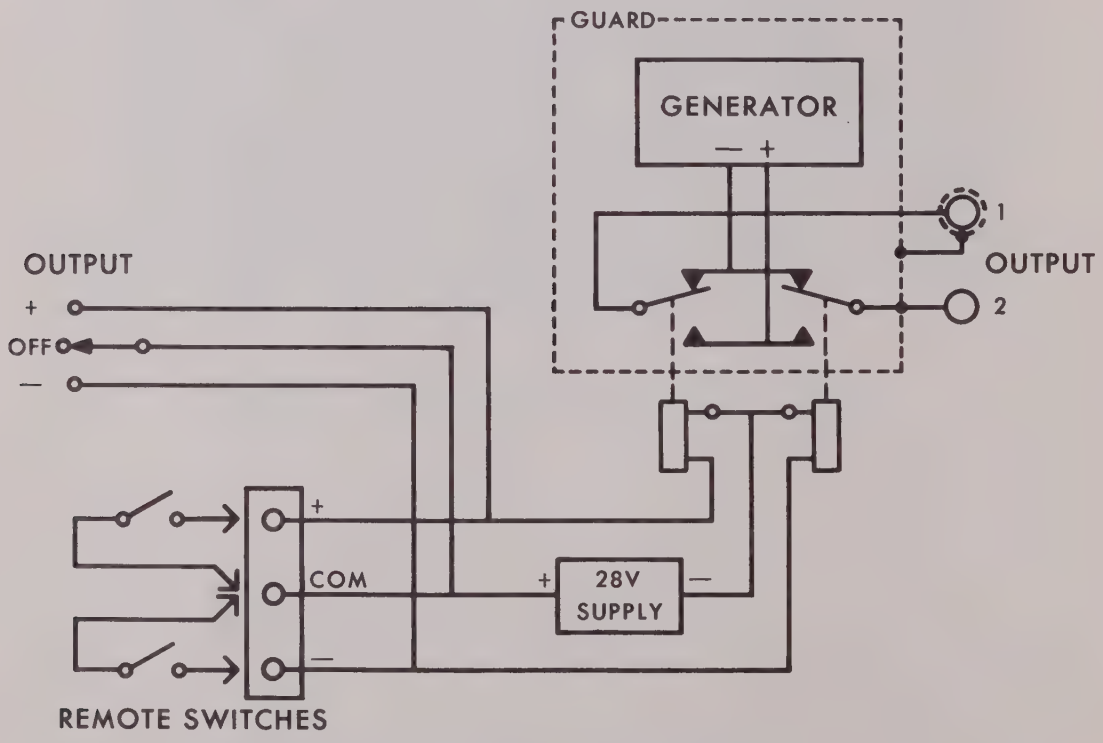

Figure 2.8 Remote Generator Control

2.10 CHANGING THE INPUT LINE VOLTAGE

The Model 801 Generator-Detector may be operated on either 117-volt or 230-volt ac power. An internal switch selects the input wiring to accommodate either voltage.

The setting of this switch at the time of manufacture is noted on the rear of the instrument. If the setting of the switch is not correct for the power line to be used, change the setting of the switch before plugging in the instrument.

In order to have access to the switch, remove the instrument case (paragraph 4.1.2). The switch is located on a chassis support immediately behind the upper center of the front panel. Slide the switch with a fingernail or with a small screwdriver so that it indicates 115 or 230 as appropriate.

Replace the instrument case after setting the switch, and correct the note attached to the rear of the instrument.

SECTION III

THEORY OF OPERATION

3.1 GENERATOR

The 801 generator is a line-regulated, guarded dc power supply with variable output power and a provision for matching the output impedance to a wide range of values. The guarding of the generator makes accurate high-resistance bridge measurements possible. The diagrams below illustrate how this is done.

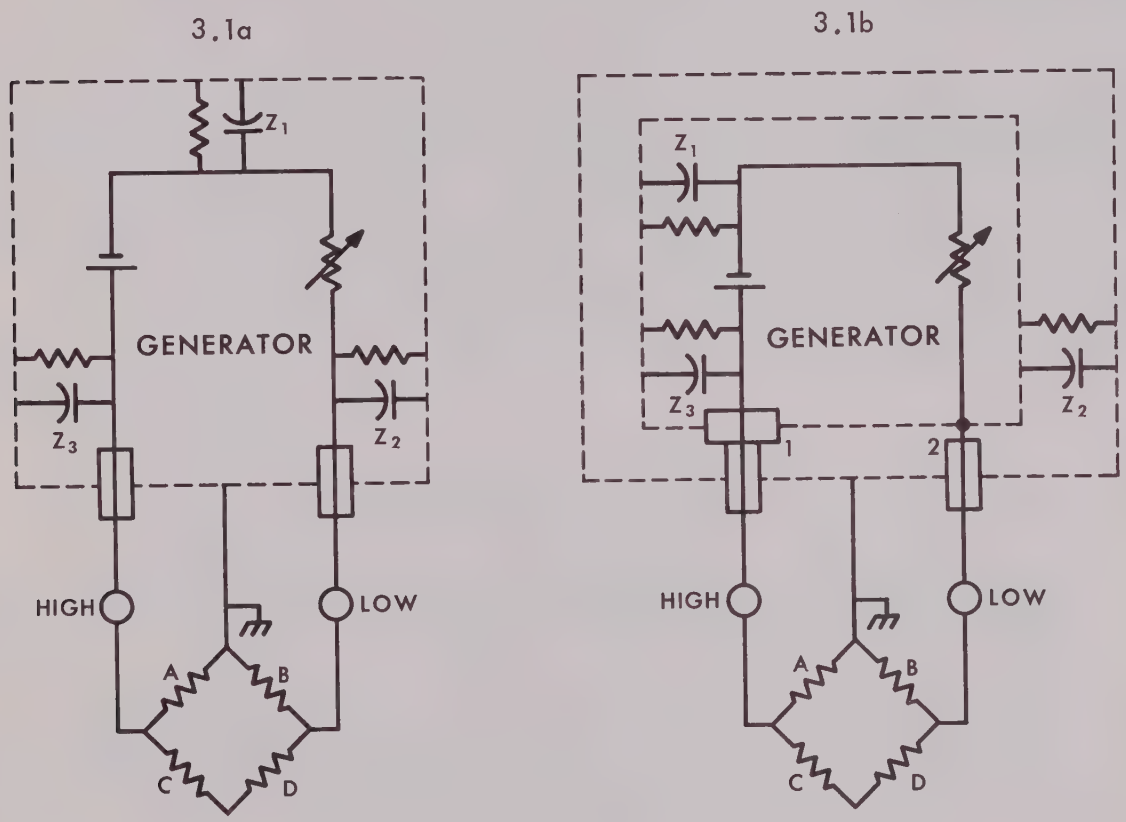

Figure 3.1 Generator Circuits

In the unguarded circuit shown in Figure 3.1a, the leakage impedances Z_2 and Z_3 appear in parallel with bridge arms A and B. If these were high-resistance arms, an appreciable error would result. The leakage impedance Z_1 is also in parallel with each of arms A and B. Since this leakage is at a higher emf than those at the terminals, it will cause even more error.

The 801 generator uses the guarded circuit as shown in Figure 3.1b. Z_1 and Z_3 appear in parallel with the generator, and cause no trouble. Z_2 is kept to better than 10^{11} ohms by use of high quality insulators, both as a feed-through insulator for the low terminal and as

support insulators for the guard chassis. By keeping bridge arm B (or whatever resistance is attached to the low terminal) small relative to 10^{11} ohms, no appreciable error is experienced. The guarding also keeps any ac voltage across Z_1 from getting into the detector via bridge arms A and B, since this ac voltage is returned to the low terminal.

The primary of the power transformer is separately shielded and air-insulated from the core to prevent capacitive coupling and leakage of ac voltages to the guard chassis. If an ac voltage were present on the guard chassis, it would appear from the low output terminal to ground and, thus, directly across the bridge arm B (Figure 3.1) in bridge measurements. The ac would then appear on the detector and would cause an error in null reading. The separate shielding of the transformer is connected to ground to prevent this error.

The generator is line-operated and has a solid-state line voltage regulator. The input voltage, which may be 117 volts or 230 volts ac, is increased (if necessary) by the input transformer to 230 volts. This voltage is clipped by the line regulator to 117 volts, which is applied to a continuously-variable autotransformer. The autotransformer output is applied to a high-isolation guarded transformer which supplies power to the rectifier and filter networks. Filtered dc is supplied to the output terminals through various resistances. The resistances and output voltages are selected by the generator RANGE selector. Each voltage and resistance combination is calculated to allow no more than one watt in any measurement circuit connected to the generator terminals.

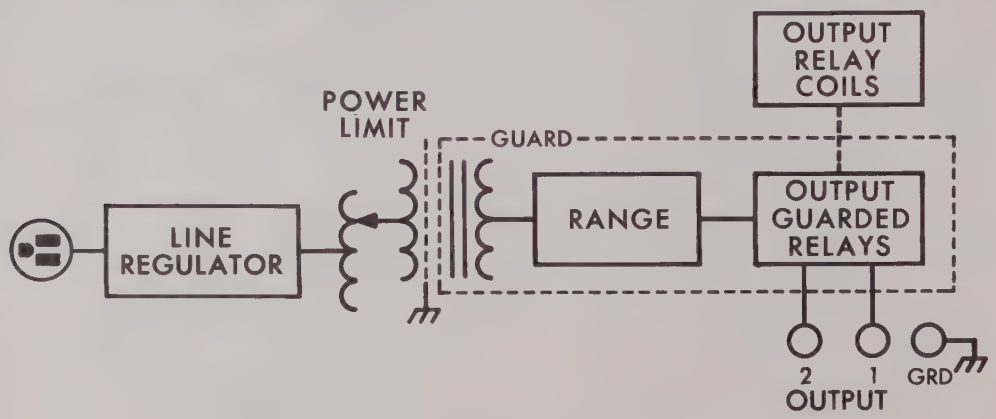

Figure 3.2 Generator Simplified Circuit

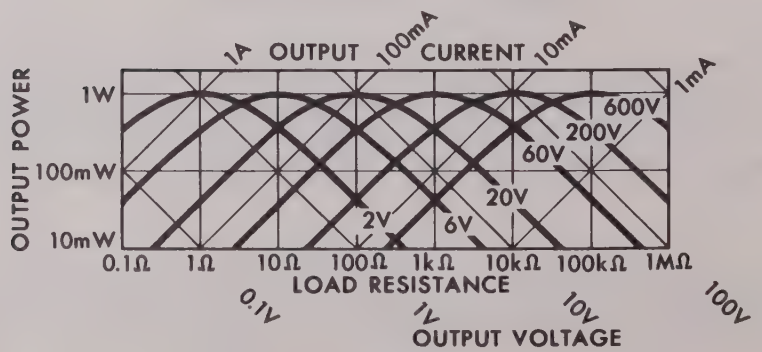

Figure 3.3 Generator Output

3.2 DETECTOR

The detector of the Model 801 is a high-sensitivity solid-state dc voltmeter. It has the following basic circuits: (1) an input attenuator, (2) a modulator and demodulator, (3) an ac amplifier, (4) a dc amplifier, (5) a meter, and (6) a feedback control circuit. Figure 3.4 is a block diagram of the detector.

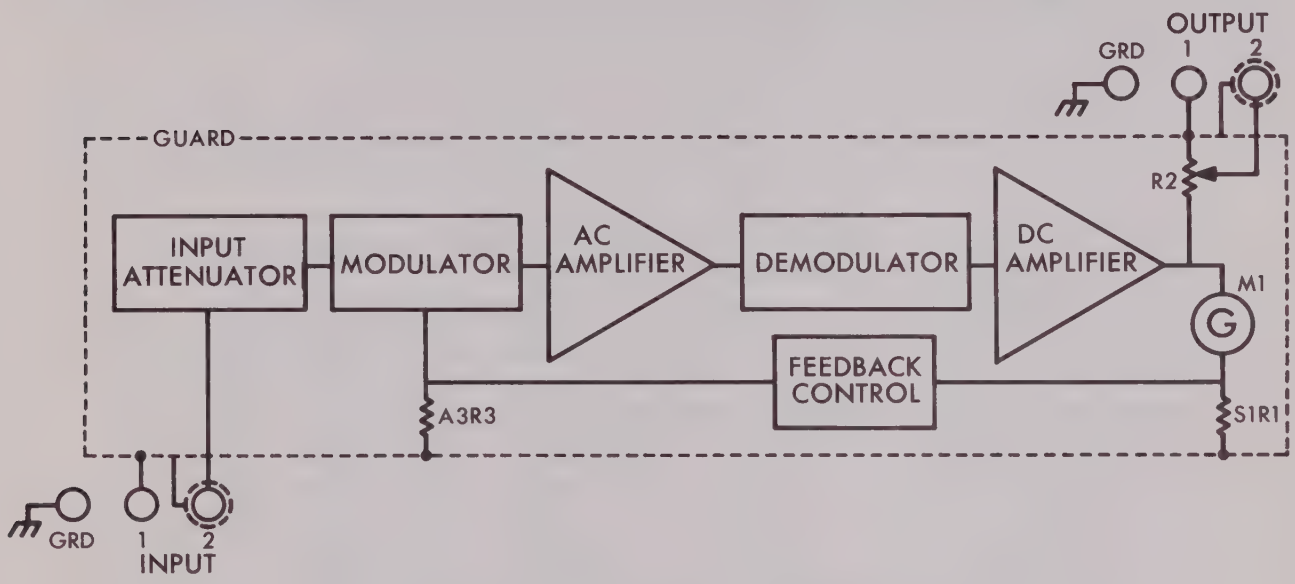

Figure 3.4 Detector Block Diagram

A dc voltage measured by the detector is applied to the input attenuator, which is a resistive divider operated by the RANGE switch. Table 3.1 lists the attenuation factors for each range.

The dc output of the input attenuator is modulated by the modulator, which consists of two photocells that are alternately illuminated by two neon lamps. The output of the modulator is a square wave with an amplitude that is proportional to the amplitude of the dc input voltage.

The square wave output of the modulator is amplified by a six-stage, high-gain ac amplifier. The output of the ac amplifier is applied to the demodulator. The demodulator output is a dc voltage with an amplitude proportional to the square-wave output of the ac amplifier. The output of the demodulator is applied to a three-stage dc voltage and power amplifier. The gain provided by the ac and dc amplifiers is listed for each range in Table 3.1.

The output of the dc amplifier, approximately 1 volt full scale, is applied to the meter and to the OUTPUT terminals on the front of the panel.

The feedback control circuit consists of a resistive voltage divider controlled by the RANGE switch and a SENSITIVITY control. When the SENSITIVITY control is in the CALIBRATED

position, it is disconnected, and only the voltage divider has any effect. The feedback provided by the feedback control circuit with SENSITIVITY at CALIBRATED is listed for each range in Table 3.1. Subtracting the feedback from the open-loop gain gives the closed-loop gain. The closed-loop gain, in conjunction with the input attenuation factor provides 18 calibrated full scale ranges from 3 microvolts to 1000 volts. When the SENSITIVITY control is not in the CALIBRATED position, it reduces the feedback and thus increases the closed-loop gain. By thus reducing the feedback, the sensitivity of the detector can be increased to about four times the calibrated sensitivity.

Table 3.1 Amplifier Characteristics

RANGE	ATTENUATION FACTOR	OPEN LOOP GAIN	FEEDBACK
3 μV	1:1	150 dB	40 dB
10 μV	1:1	150 dB	50 dB
30 μV	1:1	150 dB	60 dB
100 μV	1:1	150 dB	70 dB
300 μV	1:1	130 dB	60 dB
1000 μV	1:1	130 dB	70 dB
3 mV	1:1	120 dB	70 dB
10 mV	10:1	120 dB	60 dB
30 mV	10:1	120 dB	70 dB
100 mV	10^2:1	120 dB	60 dB
300 mV	10^2:1	120 dB	70 dB
1000 mV	10^3:1	120 dB	60 dB
3 V	10^3:1	120 dB	70 dB
10 V	10^4:1	120 dB	60 dB
30 V	10^4:1	120 dB	70 dB
100 V	10^5:1	120 dB	60 dB
300 V	10^5:1	120 dB	70 dB
1000 V	10^6:1	120 dB	60 dB

SECTION IV

MAINTENANCE

4.1 PREVENTIVE MAINTENANCE

The following procedures should be performed periodically (approximately once a year) to insure maximum accuracy and reliability from the Model 801 Generator-Detector.

If the need for major repairs is apparent, it is recommended that the unit be sent to the factory for service. The service department will be glad to furnish the necessary information for repairs as well as any replacement parts. However, unauthorized repairs will invalidate the instrument warranty.

4.1.1 Visual Inspection

Inspect the unit for dial orientation and damage to binding posts and binding post caps. Also check for dirt around the binding post insulators. Then remove the case as described in Paragraph 4.1.2 and inspect the unit for possible internal defects. These defects include such things as loose or broken connections, damaged or dirty switch contacts, and heat-damaged resistors.

4.1.2 Removing the Case

Prepare a soft, clean place to set the instrument. Be sure that no projections or pointed objects will be underneath the panel. See that there are no metal filings in the area.

Place the unit face down on the prepared surface. Remove the screws on the back of the instrument and carefully slide the case off.

4.1.3 Cleaning and Lubrication

Clean the front panel with a soft, dry, lint-free cloth, being particularly careful to remove all dirt from around the binding post insulators. The only internal components that require cleaning and lubrication are the switches.

The switches are carefully lubricated at the time of manufacture and are protected from contamination by the instrument case. They should rarely, if ever, require maintenance. It is recommended that they be cleaned or lubricated only if it is determined that they are not making good electrical contact. If the switch decks are in need of cleaning or lubrication, proceed as follows:

a) Apply solvent (Freon printed circuit solvent or equivalent) to the contact surfaces with a small brush or pipe cleaner.

b) Wipe surfaces with clean, dry brush or dry with low-pressure air.

c) Apply a thin coating of lubricant (Oak #2008 or equivalent) to the contact surfaces with a hypodermic needle.

d) Apply two drops of the same oil to each of the switch bearings and detent mechanisms.

e) Remove excess oil with a clean, dry cloth and remove all traces of lint with a soft brush.

4.1.4 Replacing the Case

Be sure that the interior of the case is completely clear of all foreign material. Slip the case over the unit and replace the screws.

4.2 PERFORMANCE TESTS

The performance tests presented in this section are front panel procedures designed to compare the Model 801 with its published specifications. These tests may be incorporated in periodic maintenance, post repair, and incoming quality control inspection. These tests should be conducted before any attempt is made at instrument calibration.

The test equipment required for maintenance of the Model 801 is listed in Table 4.1. Equipment having similar characteristics may be substituted for the equipment listed.

Table 4.1 Test Equipment Required

INSTRUMENT TYPE	REQUIRED CHARACTERISTICS	USE	RECOMMENDED MODEL
Potentiometric Voltmeter	DC Voltage Range: 1μV to 500 V Accuracy: ±0.2%	Accuracy Test, Response Test, and Alignment	ESI Model 300 PVB®

4.2.1 Accuracy Performance Test

The accuracy performance test setup is illustrated in Figure 4.1.

a) Connect test setup illustrated in Figure 4.1a and set potentiometric voltmeter to operate as a voltage source.

b) Make control settings indicated in Step 1 of Table 4.2. If detector reading is not within tolerances listed, perform full-scale calibration procedure (paragraph 4.4.3).

c) Repeat Step b for Steps 1 through 13 in Table 4.2.

d) Connect a wire from generator OUTPUT terminal 1 to detector INPUT terminal 2, and a wire from generator OUTPUT terminal 2 to detector INPUT terminal 1. See Figure 4.1b.

e) Set the potentiometric voltmeter to measure voltage.

f) Make the control settings indicated in Step 14 of Table 4.2 and adjust generator POWER LIMIT and RANGE controls to null the potentiometric voltmeter. If detector reading is not within tolerances listed, perform full-scale calibration procedure (paragraph 4.4.3).

g) Repeat Step f for Steps 14 through 18 in Table 4.2.

Table 4.2 Accuracy Performance Test

STEP	POTENTIOMETRIC VOLTMETER SETTINGS		MODEL 801	
	MULTIPLIER	DECADE DIALS	DETECTOR RANGE	DETECTOR READING
1	VOLTS × 0.01	0.0003	3 μV	2.75 to 3.35
2	VOLTS × 0.1	0.0001	10 μV	9.40 to 10.60
3	VOLTS × 0.1	0.0003	30 μV	2.84 to 3.16
4	VOLTS × 0.1	0.0010	100 μV	9.49 to 10.51
5	VOLTS × 0.1	0.0030	300 μV	2.85 to 3.15
6	VOLTS × 1	0.0010	1000 μV	9.50 to 10.50
7	VOLTS × 1	0.0030	3 mV	2.85 to 3.15
8	VOLTS × 1	0.0100	10 mV	9.50 to 10.50
9	VOLTS × 1	0.0300	30 mV	2.85 to 3.15
10	VOLTS × 1	0.1000	100 mV	9.50 to 10.50
11	VOLTS × 1	0.3000	300 mV	2.85 to 3.15
12	VOLTS × 1	1.0000	1000 mV	9.50 to 10.50
13	VOLTS × 1	3.0000	3 V	2.85 to 3.15
14	VOLTS × 10	1.0000	10 V	9.50 to 10.50
15	VOLTS × 10	3.0000	30 V	2.85 to 3.15
16	VOLTS × 100	1.0000	100 V	9.50 to 10.50
17	VOLTS × 100	3.0000	300 V	2.85 to 3.15
18	VOLTS × 100	5.0000	1000 V	4.50 to 5.50

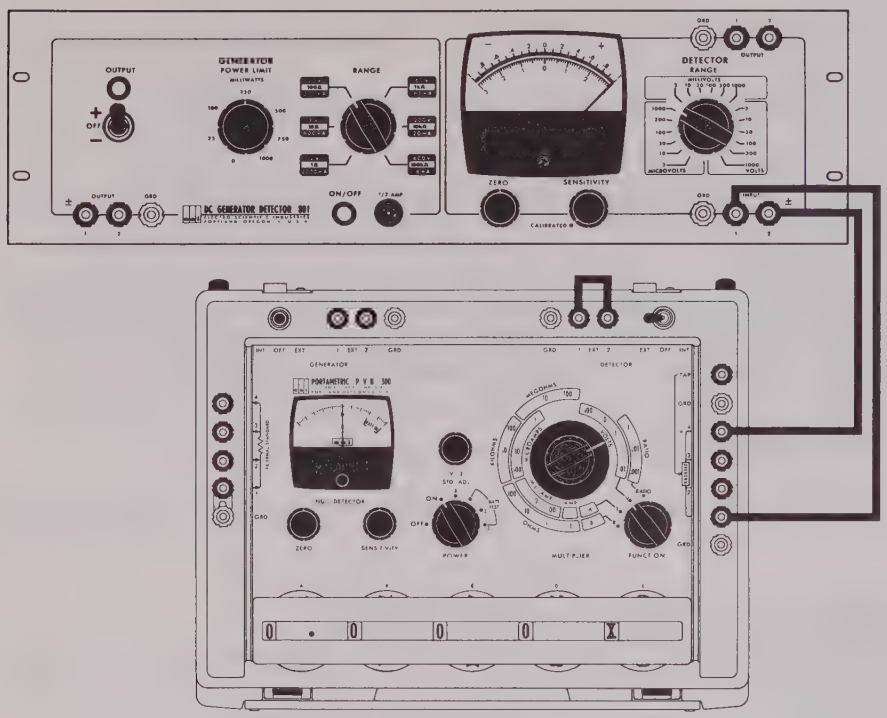

Figure 4.1a Detector Accuracy Test

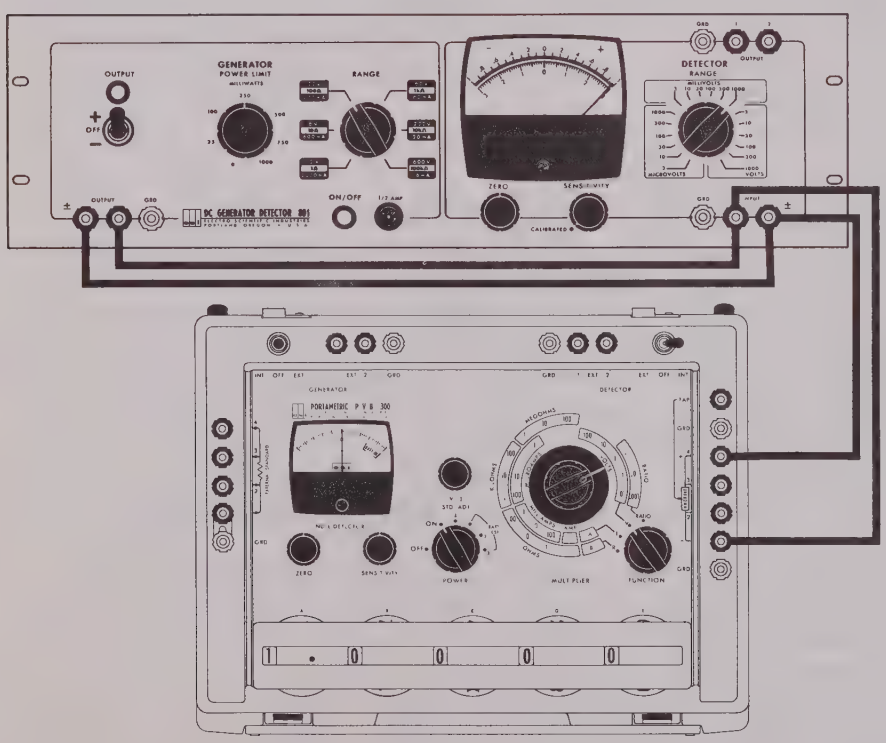

Figure 4.1b Detector Accuracy Test

4.2.2 Noise Performance Test

To determine whether detector noise is excessive, proceed as follows:

1. Short-circuit detector INPUT terminals.
2. Set detector RANGE control to 3 MICROVOLTS, and SENSITIVITY control to CALIBRATED.
3. Zero the detector.
4. Observe the meter for three successive 10-second periods. For at least one of these periods, the meter pointer should not vary more than 0.15 microvolt peak-to-peak; it should stay within a 3-minor-division interval.

4.2.3 Generator Voltage Check

Check on a one-year basis the output voltages for each generator range. This is done as follows:

1. Turn instrument on and allow 5 minutes to warm up.
2. Turn OUTPUT switch to OFF.
3. Set generator RANGE control to 1 ohm.
4. Set POLARITY to + .
5. Connect detector INPUT to generator OUTPUT terminals.
6. Set generator POWER LIMIT control to maximum.
7. Read voltage using the detector as a voltmeter.
8. Repeat all steps for all other settings of the generator RANGE control.

The voltages should be:

Range	Voltage
1Ω	1.6 to 2.4 V
10Ω	5.0 to 7.6 V
100Ω	10 to 24 V
1kΩ	50 to 76 V
10kΩ	160 to 240 V
100kΩ	500 to 760 V

4.2.4 Generator Leakage Resistance Check

To check the leakage resistance from each generator terminal to ground:

1. Connect jumper strap between detector INPUT terminal 1 and ground.
2. Connect generator OUTPUT terminal 1 to detector INPUT terminal 2 with shielded lead and plug.
3. Cover generator OUTPUT terminal with a grounded shield. Make sure that the shield does not touch the terminal.
4. Set detector SENSITIVITY control to CALIBRATED, and detector RANGE to 1000 MILLIVOLTS.

5. Set generator RANGE to 600 V, turn POWER LIMIT control fully clockwise, and set OUTPUT switch to + .
6. Meter should indicate less than 600 millivolts. (This indicates resistance greater than 10^{11} ohms.)
7. Set OUTPUT switch to OFF and connect generator OUTPUT terminal 2 to detector INPUT terminal 2 using shielded cable and plug. Again, as in test above, do not let plug touch terminal.
8. Set detector RANGE to 3 MICROVOLTS and generator RANGE to 600 V.
9. Set generator OUTPUT switch to + and turn POWER LIMIT control fully counterclockwise. Do not be concerned if meter indication goes off scale; it should be back on scale in a few seconds.
10. Within 30 seconds, the meter should indicate not more than 0.6 microvolt. (This indicates resistance greater than 10^{14} ohms.)

4.2.5 Detector Leakage Check

To check leakage resistance from each detector terminal to ground:

1. Disconnect any ground strap or jumper between either detector INPUT or OUTPUT terminals and ground.
2. Connect a jumper strap between generator OUTPUT terminal 2 and ground.
3. Connect generator OUTPUT terminal 1 to detector INPUT terminal 2 with a shielded lead and plug.
4. Cover detector INPUT terminal 1 with a grounded shield. Make sure that the shield does not touch the terminal.
5. Set detector SENSITIVITY control to CALIBRATED, and detector RANGE to 1000 MILLIVOLTS.
6. Turn generator RANGE and POWER LIMIT controls fully clockwise, and set OUTPUT switch to + .
7. Meter should indicate less than 600 millivolts. (This indicates resistance greater than 10^{11} ohms.)
8. Set OUTPUT switch to OFF and connect generator OUTPUT terminal 2 to detector INPUT terminal 1 using shielded cable and plug.
9. Set detector RANGE to 3 MICROVOLTS and generator RANGE to 600 V.
10. Set generator OUTPUT switch to + and turn POWER LIMIT control fully counterclockwise. Do not be concerned if meter indication goes off scale; it should be back on scale in a few seconds.
11. Within 30 seconds, the meter should indicate not more than 0.6 microvolt. (This indicates resistance greater than 10^{14} ohms.)

4.3 DETECTOR

4.3.1 Removing Inner Covers

The generator and the detector have inner covers to provide complete guarding and shielding of components. To remove the generator covers (top and bottom), remove the four screws holding each cover plate. To remove the detector cover, remove the two screws on the rear of the cover and slide the U-shaped cover backward, being careful not to scrape the circuit boards.

4.3.2 Servicing Etched Circuit Boards

CAUTION

REMOVE THE FIVE COLORED WIRES FROM
THE CIRCUIT CARDS IN THE DETECTOR
BEFORE UNPLUGGING THE CARDS.

The Model 801 has etched circuit boards. Use caution when removing them to avoid damaging mounted components. The assembly and Hewlett-Packard or ESI part number are on the circuit board to identify it.

The detector etched circuit boards are a plated-through type. The electrical connection between sides of the board is made by a layer of metal plated through the component holes. When working on these boards, observe the following general rules:

a) Use a low-heat (25 to 50 watts) small-tip soldering iron and a small-diameter rosen-core solder.

b) Circuit components can be removed by placing the soldering iron on the component lead on either side of the board and pulling up on lead. If a component is obviously damaged, clip leads as close to component as possible and then remove. Excess heat can cause the circuit and board to separate or cause damage to the component.

c) Component lead hole should be cleaned before inserting new lead.

d) To replace components, shape new leads and insert them in holes. Reheat with iron and add solder as required to insure a good electrical connection.

e) Clean excess flux from the connection and adjoining area.

f) To avoid surface contamination of the printed circuit, clean with weak solution of warm water and mild detergent after repair. Rinse thoroughly with clean water. When completely dry, spray lightly with Krylon (#1302 or equivalent).

4.4 ADJUSTMENT AND CALIBRATION

4.4.1 Mechanical Zero Adjustment

The mechanical zero adjustment is located on the instrument front panel. If the meter pointer does not indicate zero when the instrument power has been off for at least one minute, mechanically zero the meter by turning the screwdriver adjustment on the meter.

4.4.2 Electrical Zero Adjustment

The electrical zero adjustment should be performed when the meter pointer does not indicate zero on the 1000-millivolt range when instrument power has been on for at least one minute. No external equipment is required for this adjustment.

a) Set detector RANGE control to 1000 MILLIVOLTS.

b) Short-circuit INPUT terminals.

c) Remove the case; adjust A1R14 (1 V ZERO) for zero deflection on meter.

4.4.3 Full-Scale Calibration

The full-scale calibration consists of performing the 3 μV, 10 μV, 1 mV and 1 V adjustments.

a) Connect test setup illustrated in Figure 4.1a.

b) Remove the case

c) Set Potentiometric Voltmeter for 3 μV output; adjust A1R41 (3 μV) for full-scale deflection on 3 μV range.

d) Set Potentiometric Voltmeter for 10 μV output; adjust A1R42 (10 μV) for full-scale deflection on 10 μV range.

e) Set Potentiometric Voltmeter for 1 mV output; adjust A1R43 (1 MV) for full-scale deflection on 1000 μV range.

f) Set Potentiometric Voltmeter for 1 V output; adjust A1R44 (1 V) for full-scale deflection on 1000 mV range.

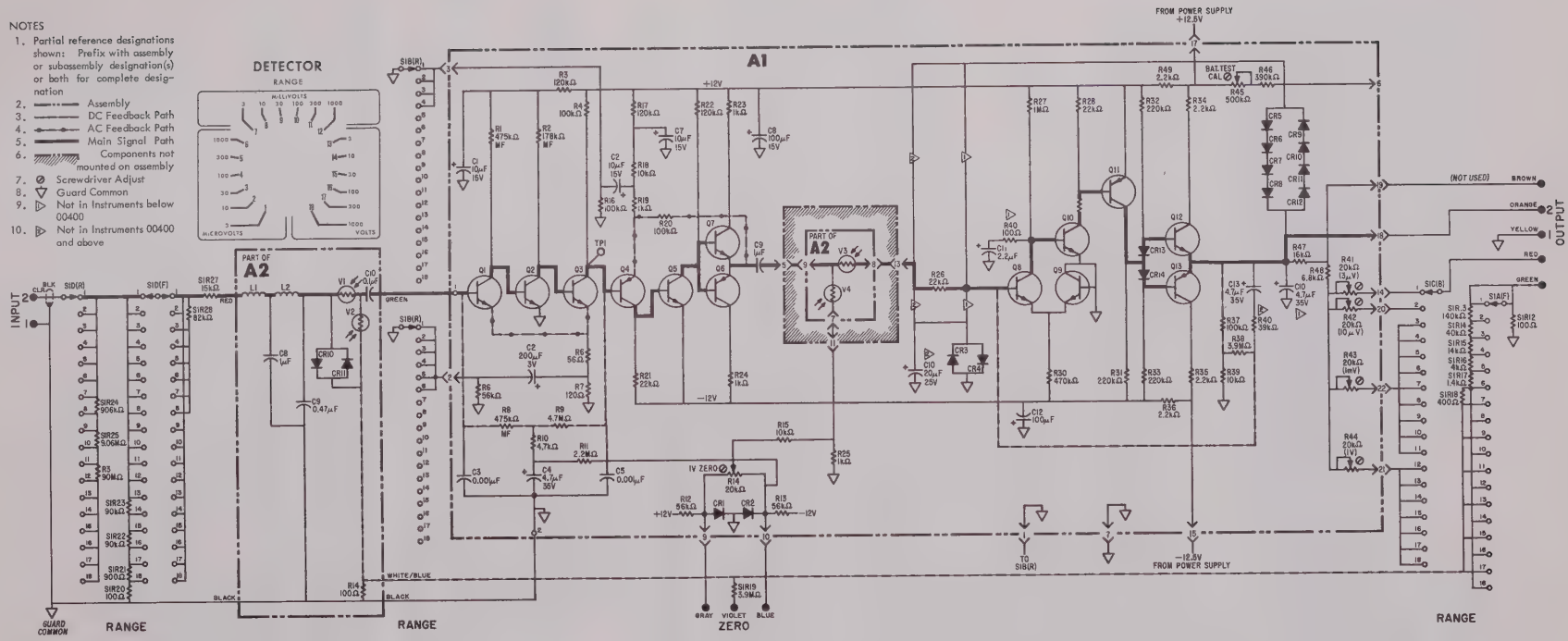

Figure 4.2 Detector, Schematic Diagram

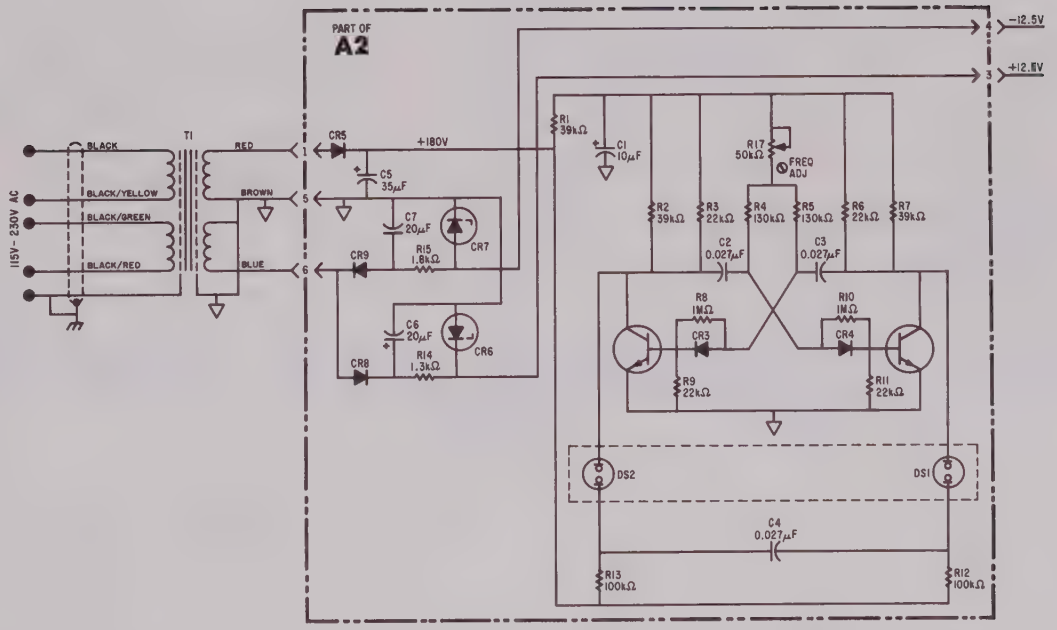

Figure 4.3 Detector Power Supply and Lamp Driver, Schematic Diagram

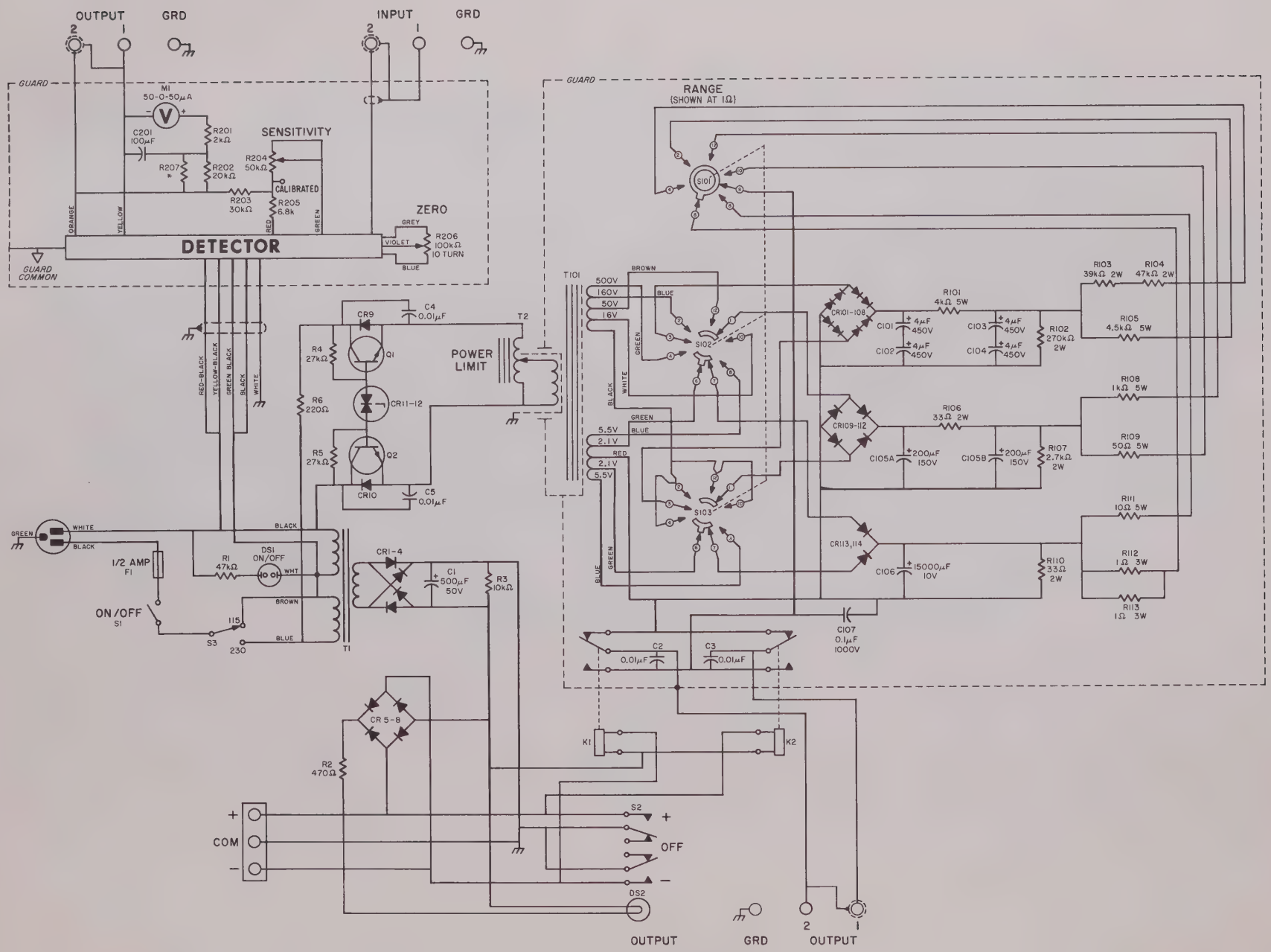

Figure 4.4 Schematic Diagram

4.5 PARTS LIST

The following parts are listed in two groups: those with and those without circuit reference designators. The parts in each group are listed alphabetically by description of part. See Figure 4.4 for reference designators.

All parts on this list may be obtained from Electro Scientific Industries, Inc. When ordering parts, include the following information:

Model and serial number of the instrument (Model 801)

Electro Scientific Industries part number

Circuit reference designator (where applicable)

Description of part

CKT REF	DESCRIPTION	PART NO.	QTY USED
C2-5	Capacitor, 0.01μF, 1000V	1918	4
C107	Capacitor, 0.1μF, 1000V	50013	1
C201	Capacitor, 100μF, 12V	6157	1
C101-104	Capacitor, 4μF, 450V	2183	4
C105 A&B	Capacitor, 200μF, 150V, 10%	2138	2
C1	Capacitor, 500μF, 50V	1942	1
C106	Capacitor, 1500μF	8035	1
A1	Detector Amplifier Circuit Assembly	18409	1
A2	Detector Power Supply Circuit Assembly	18408	1
CR1-10, 101-114	Diode, Type 1N 4005 or equal	1779	24
CR11, 12	Diode, Zener, 160 volts	18453	2
F1	Fuse, 1/2 amp	1802	1
M1	Meter	18410	1
DS2	Pilot Light, Generator OUTPUT	18412	1
R206	Potentiometer, 100kΩ, 10 Turn, ZERO	18414	1
R204	Potentiometer Switch Assembly, 50kΩ, SENSITIVITY	18413	1
T2	Variable Autotransformer, POWER LIMIT	8068	1
K1, 2	Relay, Guarded	18439	2
R112, 113	Resistor, 1Ω, 3 watts, 5%	2036	2
R111	Resistor, 10Ω, 5 watts, 5%	2040	1
R106,109,110	Resistor, 33Ω, 2 watts, 10%	2045	2
R109	Resistor, 50Ω, 5 watts, 5%	2047	1
R2	Resistor, 470Ω, 1/2 watt, 10%	2056	1
R6	Resistor, 220Ω, 2 watts, 10%	50015	1
R108	Resistor, 1kΩ, 5 watts, 5%	2061	1
R201	Resistor, 2kΩ, 1/2 watt, 1%	2062	1
R107	Resistor, 2.7kΩ, 2 watts, 10%	2065	1
R101	Resistor, 4kΩ, 5 watts, 5%	2484	1
R105	Resistor, 4.5kΩ, 5 watts, 5%	2070	1
R205	Resistor, 6.8kΩ, 1/2 watt, 10%	2075	1
R3	Resistor, 10kΩ, 1/2 watt, 10%	1961	1
R202	Resistor, 20kΩ, 1/2 watt, 1%	1987	1
R4, 5	Resistor, 27kΩ, 1/2 watt, 10%	1962	2

CKT REF	DESCRIPTION	PART NO.	QTY USED
R203	Resistor, 30kΩ, 1/2 watt, 1%	2458	1
R103	Resistor, 39kΩ, 2 watts, 10%	2469	1
R1	Resistor, 47kΩ, 1/2 watt, 10%	1958	1
R104	Resistor, 47kΩ, 2 watts, 10%	2474	1
R102	Resistor, 270kΩ, 2 watts, 10%	1645	1
S-3	Switch, DPDT, (115-230)	18424	1
S101-103	Switch, Generator RANGE	8050	1
S2	Switch, Lever, Generator OUTPUT	3071	1
S1/DS1	Switch and Pilot Light Assembly, ON/OFF	18418	1
Q1, 2	Transistor, Type 40318 or equal	18452	2
T101	Transformer, Generator	8091	1
T1	Transformer, Relay Supply	18445	1
	Barrier Strip, 3 Terminal	18415	1
	Binding Post, Guarded	1480	3
	Binding Post, 1 inch long	1396	6
	Cap, Binding Post, Black	1170	6
	Cap, Binding Post, Gold Plated	1172	3
	Detector Assembly	18411	1
	Dust Cover	18446	1
	Fuseholder	18416	1
	Generator Power Supply Assembly	18420	1
	Knob, Large Bar, Filled	1266	2
	Knob, Large Round, Filled	1271	1
	Knob, Small Round, Filled	1268	1
	Knob, Small Round	1255	1
	Panel, Front	18419	1
	Power Cord	2520	1
	Printed Circuit Board Assembly, Capacitor	18433	1
	Printed Circuit Board Assembly, Diode	18435	1
	Printed Circuit Board Assembly, Meter	18449	1
	Printed Circuit Board Assembly, Relay Power	18437	1
	Shaft Coupler, Insulating	8053	2

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A NEW APPROACH TO BRIDGE SENSITIVITY

by
Jack Riley

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A NEW APPROACH TO BRIDGE SENSITIVITY

Ever since Christie invented the Wheatstone bridge in 1833, people have been concerned with bridge sensitivity. In 1862, Thomson released a paper describing his Kelvin double bridge (1). The sensitivity analysis in his paper is believed to be the first published. He concluded that the heating effect of the test current was the limiting factor. This conclusion was overlooked for the next three decades mostly because of the low quality of the batteries available for powering bridge circuits. Schwindler, in 1866, Heaviside in 1873, and Gray in 1881, all attempted bridge sensitivity analysis. The second and third editions of Maxwell's "Electricity and Magnetism," published in 1892, include a section on bridge sensitivity. The modern approach to bridge sensitivity analysis is given by Wenner (1) in Volume 25 of the "Journal of Research of the National Bureau of Standards."

Most of the writings about bridge sensitivity finish with an impressive algebraic expression which must be evaluated for each possible setting of the bridge. This paper presents a graphical analysis offering several advantages. The calculations for a large number of bridge settings can be performed rapidly. The behavior of the bridge and its generator are separated from the performance of the detector. The suitability of various detectors can be checked in a simple manner. Sensitivity curves for different bridge and detector combinations can be constructed easily, or sensitivity can be deduced from the bridge and detector plots directly.

The graphical technique for analyzing a Wheatstone bridge is given. A typical circuit is used as an example and the performance for a particular measurement is followed through all of the steps. The performance curves for a commercially available bridge are given to show the practical application of the technique.

WHAT IS SENSITIVITY

A definition of sensitivity is needed before a bridge can be analyzed. Sensitivity is defined as the ratio of the smallest discernible change of the measured quantity to the total value of that quantity. If a 1% change in the resistance being measured produces a barely perceptible movement of the null indicator, the sensitivity is 1%.

GRAPH PAPER

Special graph paper simplifies the graphical analysis. The coordinates of this paper are log power versus log resistance, with contours of equal voltage and equal current drawn on the diagonals, as shown in Figure 1. With this paper Ohm's law and the power equation are solved simultaneously. A point plotted on this graph paper represents the resistance value of a resistor, the voltage across the resistor, the current through the resistor, and the power dissipated by the resistor.

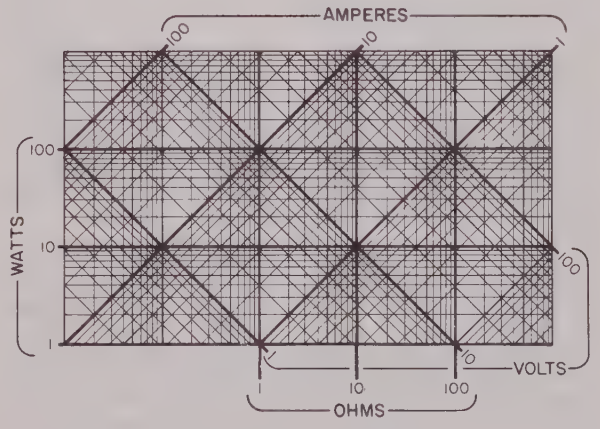


FIGURE 1. GRAPH PAPER

ANALYZING A BRIDGE

The sensitivity analysis technique can be illustrated by applying it to the bridge circuit shown in Figure 2. The

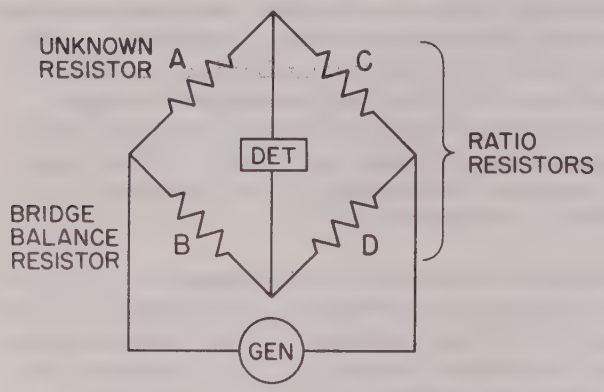


FIGURE 2. BRIDGE CIRCUIT

components for this bridge, the generator which will drive it, and the detector which is used as a null indicator are chosen, then the analysis is made. First the bridge output resistance and open-circuit voltage are found. Their effect on a detector is then studied.

THE GENERATOR

It is particularly informative to plot the equivalent Thevenin or Norton generator performance on the graph paper shown in Figure 1. For either type of equivalent circuit (and for most practical circuits) the open circuit voltage, the short circuit current and the source resistance all intersect at a single point. This can be called the "source describing point". This single point on the graph paper as shown in Figure 3 serves to completely describe the output of the generator in a manner which can be later used to find the amount of voltage or current it will actually supply to a bridge.

In Figure 3 the power supplied to the load is plotted versus the load resistance. If the load resistance is low,

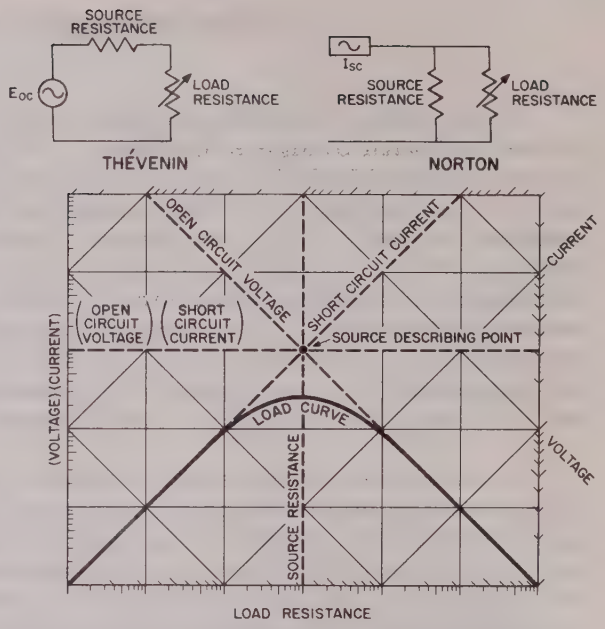
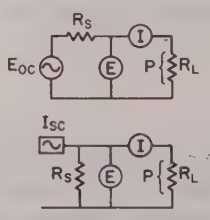


FIGURE 3. SOURCE REPRESENTATION

a constant current approximately equal to the short-circuit current is supplied. If the load resistance is high, a constant voltage approximately equal to the open-circuit voltage is supplied. The curve can be predicted on the basis of either the Thevenin equivalent generator consisting of a zero-impedance voltage source in series with a fixed resistor, or the Norton equivalent circuit consisting of an infinite impedance current source feeding a fixed internal resistance and load resistance in parallel. The load curve can be plotted from either form of equation (1).



$$P = (E_{OC})^2 \frac{R_L}{(R_L + R_S)^2}$$

$$P = (I_{SC} R_S)^2 \frac{R_L}{(R_L + R_S)^2} \qquad (1)$$

The open-circuit voltage and short-circuit current will intersect at the value of internal resistance. The power at this intersection point represents the

maximum amount of power which can be dissipated in the internal resistance of the generator. This intersection point is enough to completely describe a given generator. The curve is always the same shape and can be drawn with a template once the intersection of open circuit voltage and short-circuit current is found.

The generator chosen for the bridge shown in Figure 2 consists of three 45-volt batteries in series with a protective resistor of 4.7k. The performance of this generator is shown in Figure 4.

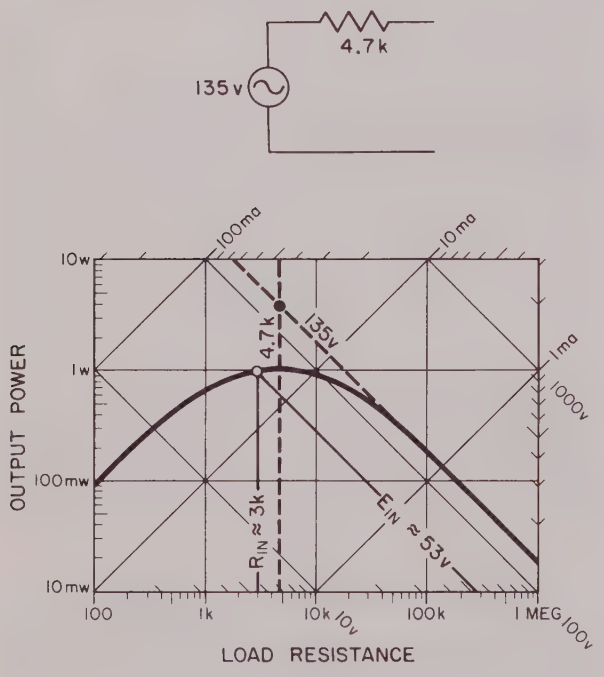


FIGURE 4. GENERATOR PERFORMANCE

When this generator is shorted, short-circuit current of about 30 ma will flow through the protective resistor causing it to dissipate about four watts. The maximum output power from the generator is approximately one watt. It cannot damage any bridge or detector components which are capable of dissipating one watt of power. This form of power protection can often be used to advantage.

If the bridge of Figure 2 is measuring a five-kilohm resistor and if resistors C and D are each one kilohm, the bridge will be a three-kilohm load. The generator will supply about 53 volts to this load as shown in Figure 4.

INPUT RESISTANCES

The bridge input resistance is needed for all values of unknown resistance to be measured. The input resistance is found by paralleling resistors A and C in series with B and D in series. At balance, resistance in the detector circuit has no effect. Equation (2) gives the input resistance.

$$R_{IN} = D\frac{(A+C)}{(D+C)} \qquad (2)$$

The curve for the input resistance also has a characteristic shape and can be drawn with a template. Two calculated values will locate the template so that the complete range of values can be plotted. If A is low, B is also low so the input will look like resistors C and D in parallel as shown in equation (3).

$$R_{IN} \xrightarrow[A,\,B \ll C,\,D]{} C\left(\frac{1}{1+\frac{C}{D}}\right) \qquad (3)$$

If A is high, the input resistance will approach the value in equation (4).

$$R_{IN} \xrightarrow[A \gg C]{} A\left(\frac{1}{1+\frac{C}{D}}\right) \qquad (4)$$

These two asymptotes will intersect when A = C. The resulting curve is plotted in Figure 5.

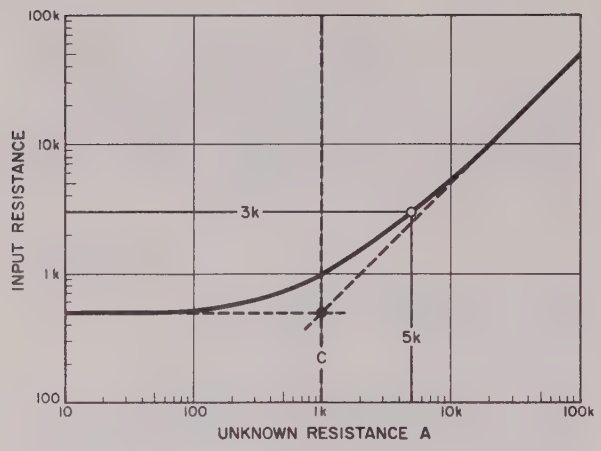


FIGURE 5. INPUT RESISTANCE

INPUT VOLTAGE

The bridge input voltage can be found from the generator performance curve (Figure 4) and the input-resist-

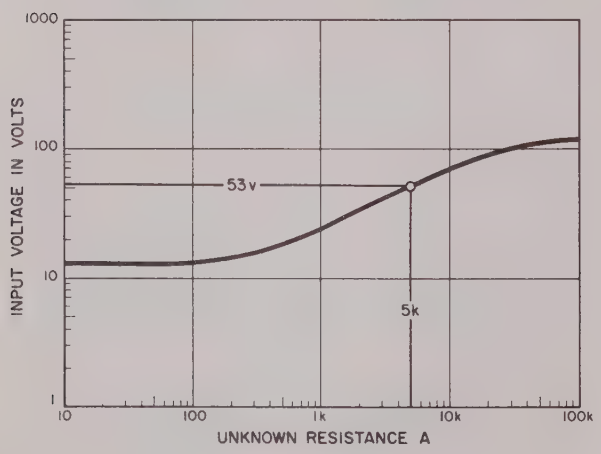


FIGURE 6. INPUT VOLTAGE

ance curve (Figure 5). The results are plotted in Figure 6. A few points are usually adequate for plotting the entire range of values.

TRANSFER FUNCTION

A transfer function can be calculated to relate the open circuit voltage at the detector terminals to the input voltage. When the bridge is balanced, there will be no voltage at the output terminals, so the bridge must be unbalanced by an amount Δ to find a signal to detect. A bridge circuit can be considered as two voltage dividers. At balance both dividers are at the same setting so that their output voltages are equal. Before the bridge is unbalanced, both of the dividers are set so that the voltage E_A across resistor A (the same voltage is also across resistor B) is related to the input voltage by equation (5). When the bridge is unbalanced by

$$\frac{E_A}{E_{IN}} = \frac{A}{A+C} \qquad (5)$$

changing the unknown resistor A to $A(1+\Delta)$ the voltage across resistor A changes to E'_A which is related to the input voltage by equation (6). The volt-

$$\frac{E'_A}{E_{IN}} = \frac{A(1+\Delta)}{A(1+\Delta)+C} \qquad (6)$$

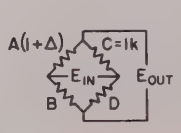
age E_A across resistor B does not change, so the difference between it and E'_A is the open-circuit output voltage E_{OUT} which is found from equation (7). Factoring equation (7) gives equa-

$$\frac{E_{OUT}}{E_{IN}} = \frac{A(1+\Delta)}{A(1+\Delta)+C} - \frac{A}{A+C} \qquad (7)$$

tion (8). When Δ is small, as it usually

$$\frac{E_{OUT}}{E_{IN}} = \frac{AC\Delta}{(A+C)^2\left(1+\frac{A\Delta}{A+C}\right)} \qquad (8)$$

is, equation (8) simplifies to equation (9) which is used for most actual calculations. The plot of equation (9) has



$$\frac{E_{OUT}}{E_{IN}\Delta} \xrightarrow{(\Delta \to 0)} \frac{AC}{(A+C)^2} \qquad (9)$$

the same shape as the power curve so that the same template can be used for drawing it. The characteristic point for drawing the curve will have an ordinate of one and an abscissa of the resistance of C. Figure 7 is a plot of

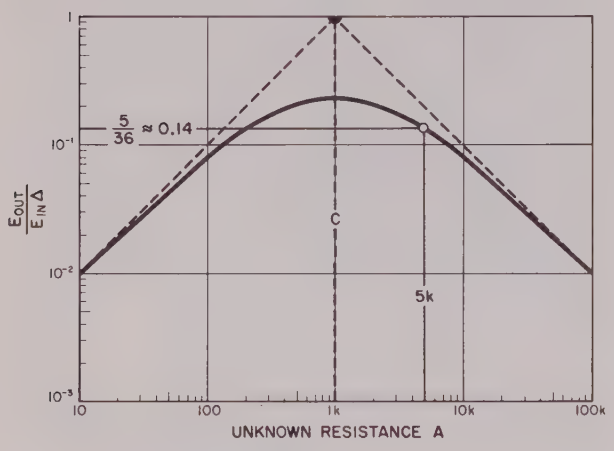


FIGURE 7. TRANSFER FUNCTION

the transfer function for the bridge of Figure 2 if C is one kilohm.

UNBALANCE Δ

The amount of unbalance Δ is a matter of choice. To find sensitivity a fixed value is assigned to Δ and the detector response is found. From this the sensitivity can be calculated. Bridge accuracy or resolution values can be assigned to Δ to find the usefulness of a detector. For the bridge being analyzed Δ is chosen as the specified accuracy and is given by equation (10).

$$\Delta = \pm (1\% + 1 \text{ DIAL DIVISION}) \qquad (10)$$

Δ is plotted in Figure 8.

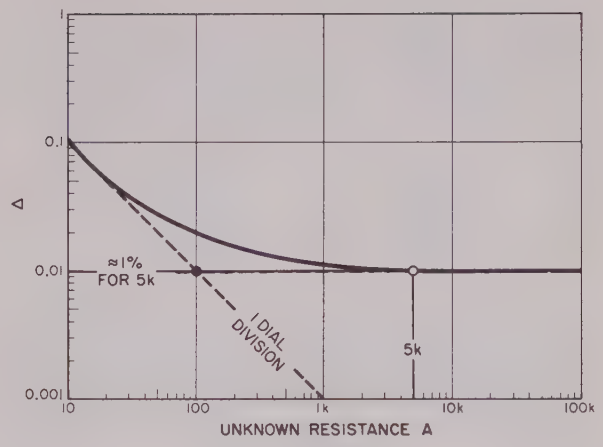


FIGURE 8. VALUES OF Δ

OUTPUT VOLTAGE

From Figures 6, 7 and 8 the output voltage can be found. Figure 9 is the plot of output voltage for the bridge of Figure 2. Both the complete curve for 1% unbalance and the curve for the combined 1% plus one dial division are shown.

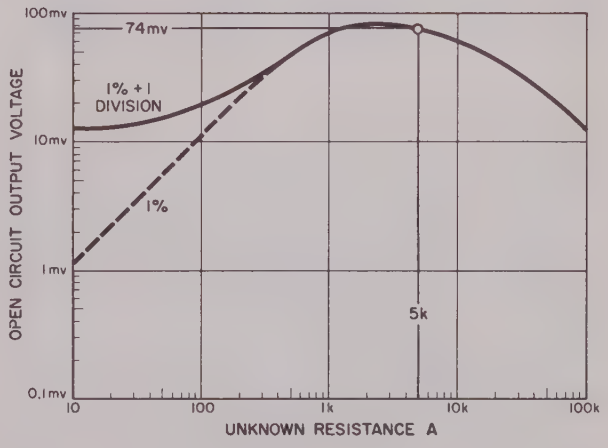


FIGURE 9. OUTPUT VOLTAGE

OUTPUT RESISTANCE

To complete the equivalent-generator circuit for the bridge output the

output resistance must be found. The output resistance is the parallel combination of A and B in series and C and D in series. At balance the output resistance is given by equation (11).

$$R_{OUT} = A\frac{(D+C)}{(A+C)} \qquad (11)$$

The curve of R_{OUT} can be plotted from two calculated values by using the template that plotted the input resistance. When A is low R_{OUT} is given by equation (12).

$$R_{OUT} \xrightarrow[A \ll C]{} A\left(1+\frac{D}{C}\right) \qquad (12)$$

When A is high the resistance becomes C and D in series as shown in equation (13).

$$R_{OUT} \xrightarrow[A \gg C]{} C\left(1+\frac{D}{C}\right) \qquad (13)$$

The asymptotes intersect at A = C. The output resistance for the bridge of Figure 2 is shown in Figure 10.

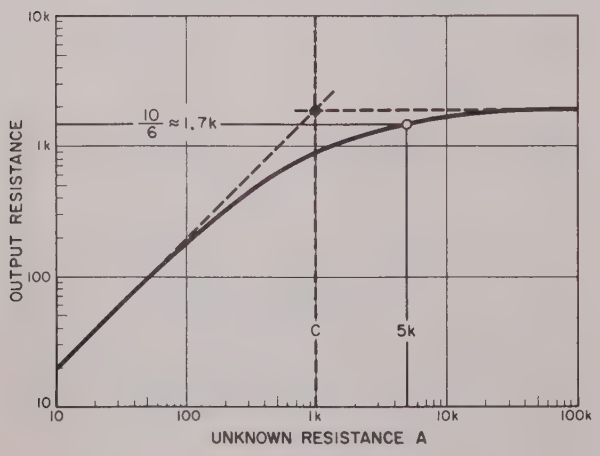


FIGURE 10. OUTPUT RESISTANCE

BRIDGE OUTPUT EQUIVALENT GENERATOR

The output voltage (Figure 9) and output resistance (Figure 10) can be combined to determine the output that the bridge will deliver to any load resistance. The output voltage and output resistance meet at the source describing point of Figure 3. The values found when measuring a five kilohm resistor have been illustrated in each of the graphs. With this measurement the output voltage is 74 millivolts and the output resistance is 1.7 kilohms. The curve showing voltage, current and power supplied by this source to various load resistances is given in Figure 11.

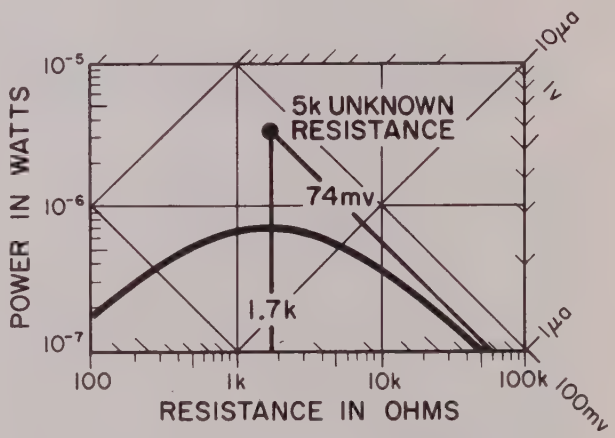


FIGURE 11. BRIDGE EQUIVALENT GENERATOR FOR ONE-PERCENT UNBALANCE WHEN MEASURING A 5k RESISTOR

Similar curves for each value of unknown resistance could be drawn. They would cover most of the paper and therefore be useless. Fortunately a plot of only the source describing points contains all of the necessary information. This graph is made by plotting the intersection points of the output voltage and output resistance for the values of unknown resistance of interest. Figure 12 is the result

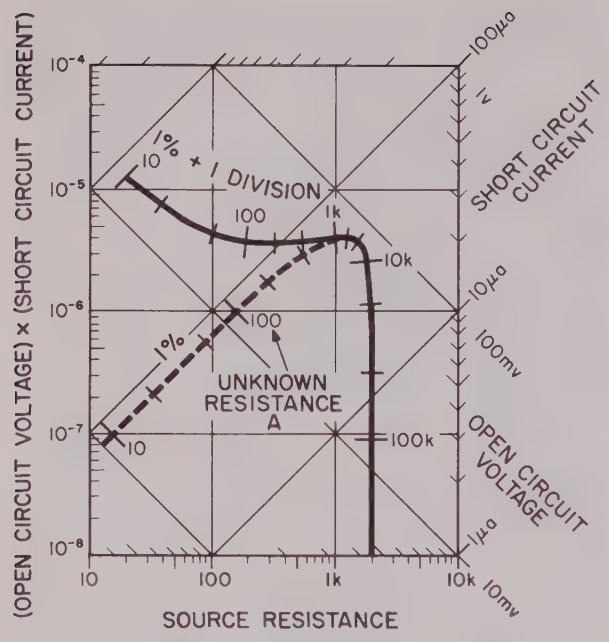


FIGURE 12. BRIDGE EQUIVALENT GENERATORS FOR ALL VALUES OF UNKNOWN RESISTANCE

The solid curve is for a Δ of ±(1% + 1 dial division). The dotted curve is for a Δ of ± 1% only.

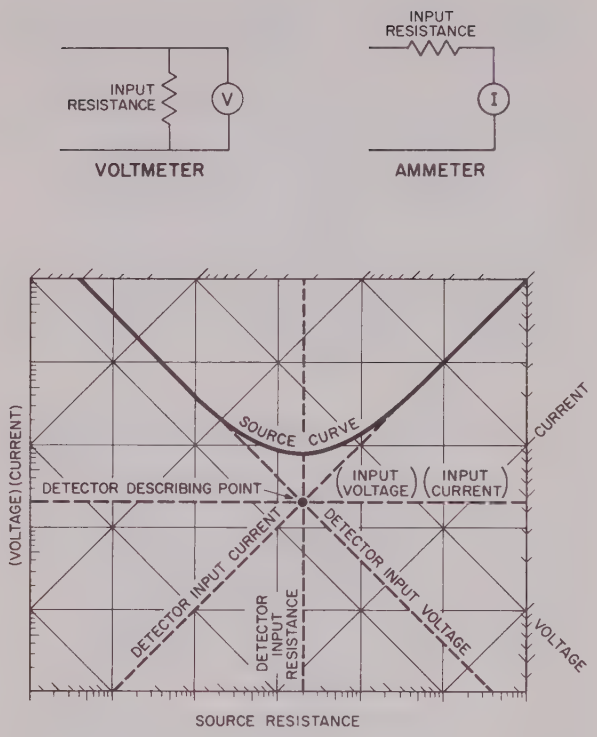


FIGURE 13. DETECTOR REPRESENTATION

THE DETECTOR

It is also possible, as shown in Figure 13, to describe one deflection of the detector by a point. The detector describing point represents its input voltage, current, and resistance for one deflection. A curve can be drawn which represents the locus of generator describing points which would produce this specified detector indication. The curve has the same shape as the generator curve, but it is inverted. If a bridge source describing point lies anywhere on the curve the detector will produce the deflection represented by the detector describing point for the curve. The detector curve can be found experimentally (or calculated) by finding which combinations of open circuit source voltage (or short circuit source current) and source resistance will give the indicated deflection of the detector. Different amounts of indication are represented by different describing points and their corresponding curves as shown in Figure 14.

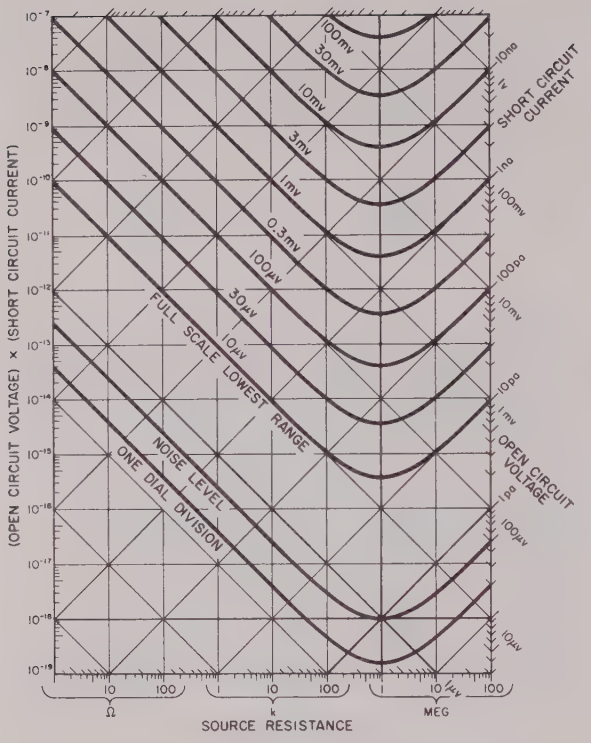


FIGURE 14. DETECTOR CURVES

BRIDGE PERFORMANCE

A generator describing point, such as those plotted in Figure 12, which is above the detector curve will produce greater deflection than that for which the curve was drawn. A generator point below the curve will not produce the indicated deflection. If the detector curve is drawn for minimum detectable deflection (noise level, smallest observable movement, etc.) it will separate generator describing points into those which can and cannot be detected. For the bridge of Figure 2 a detector with one-kilohm input resistance and a minimum observable deflection of ten millivolts was chosen. In Figure 15 this detector plot has been added to Figure 12. The sensitivity is sufficient to see rated accuracy up to about 40 kilohms of unknown resistance. If the bridge controls had sufficient resolution the detector could find one percent differences of resistors down to 100 ohms.

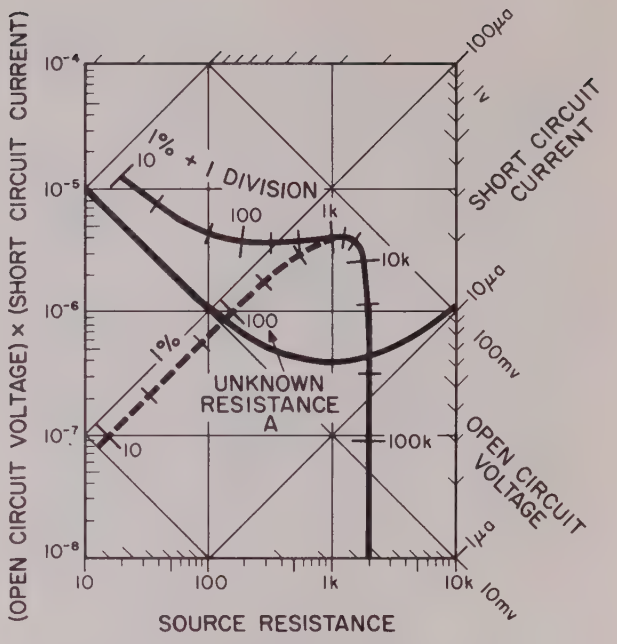


FIGURE 15. BRIDGE AND DETECTOR PERFORMANCE

SENSITIVITY CURVE

The graph provides not only qualitative data, but quantitative data as well. The bridge output voltage is almost directly proportional to Δ. The difference between the value of Δ which was chosen and the value of Δ which would supply minimum detectable signal can be found by vertical measure-

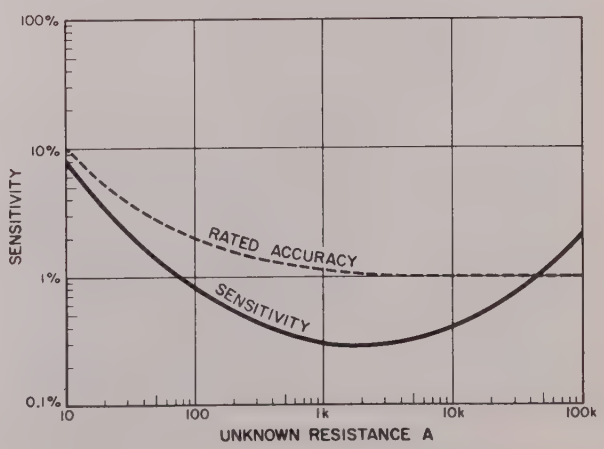


FIGURE 16. BRIDGE SENSITIVITY

ment using the voltage scale. By using this technique, the bridge sensitivity curve of Figure 16 was drawn.

The bridge sensitivity and the bridge specified accuracy are shown in similar units. Although Figure 16 is a more conventional method of presenting the data, the same information is available from Figure 15. The performance of various detectors can be demonstrated more easily by using Figure 15. To predict the performance of a new detector, one need only know its input resistance and its minimum detectable signal in terms of either current or voltage. From these data its curve can be drawn with the template.

DETECTOR COMPARISON

The type of detector curve shown in Figure 13 can also be used to compare one detector with another as shown in Figure 17. Here a rather typical collection of both ac and dc detectors is shown with their maximum sensitivity curves superimposed. It can be seen that some detectors are more sensitive for low impedance sources; others for high impedance sources. A set of describing point curves such as Figure 12, for a particular bridge or instrument can be laid over this set of curves to see which detectors have enough sensitivity for all bridge settings of interest at the required accuracy.

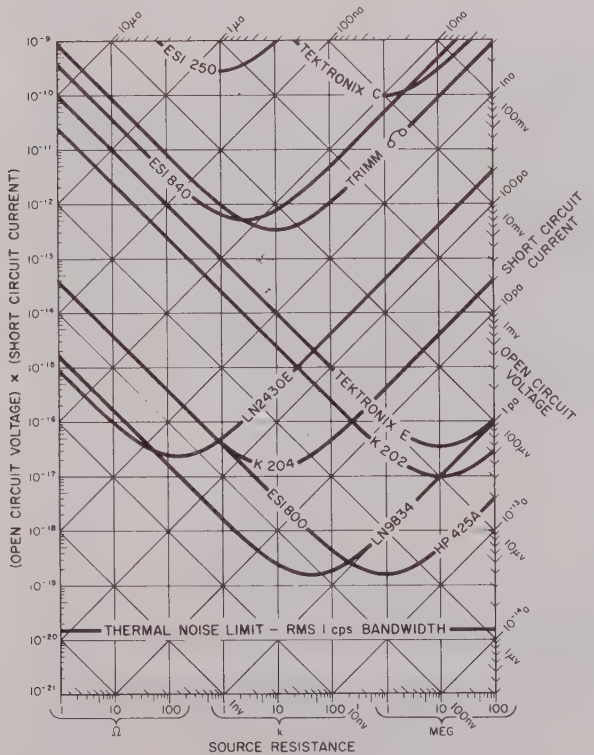


FIGURE 17. DETECTOR COMPARISON

CRITICAL DAMPING

If a low-resistance source is connected to a galvanometer the pointer movement will be extremely sluggish. If the source resistance is too high the needle will swing back and forth a long time without settling down to a final indication. To avoid these problems the source resistance can be kept constant at the critical damping value by adding series or shunt resistance. The constant source resistance requirement modifies the detector curves as shown in Figure 18.

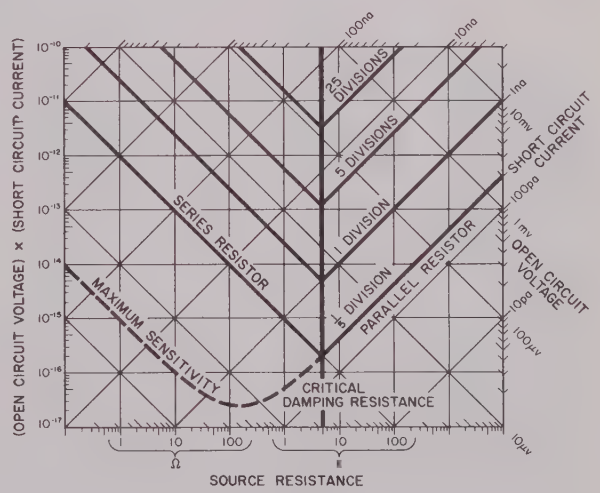


FIGURE 18. GALVANOMETER WITH 5k CRITICAL DAMPING

The dotted line at the bottom is the signal which would produce a minimum

visible deflection of one fifth dial division without the extra series damping resistance.

PERFORMANCE OF A MULTI-RANGE BRIDGE

An ESI Model 291 A Resistance Bridge Circuit has been analyzed to show the many useful aspects of the bridge-detector plots. The resulting curves are shown in Figure 19.

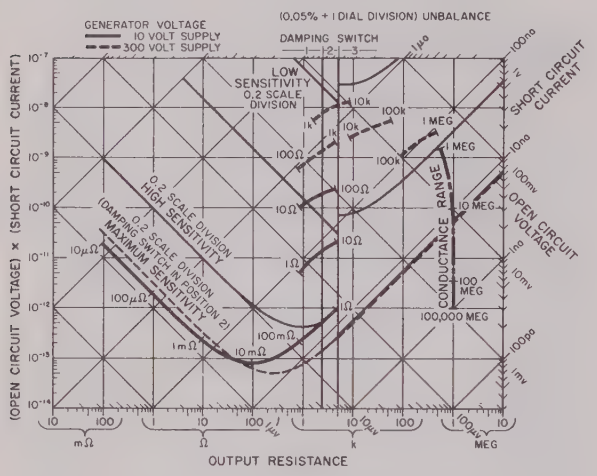

(0.05% + 1 DIAL DIVISION) UNBALANCE
GENERATOR VOLTAGE
10 VOLT SUPPLY
300 VOLT SUPPLY
DAMPING SWITCH
LOW SENSITIVITY 0.2 SCALE DIVISION
0.2 SCALE DIVISION HIGH SENSITIVITY
0.2 SCALE DIVISION (DAMPING SWITCH POSITION 2) MAXIMUM SENSITIVITY
CONDUCTANCE RANGE
SHORT CIRCUIT CURRENT
OPEN CIRCUIT VOLTAGE
(OPEN CIRCUIT VOLTAGE) x (SHORT CIRCUIT CURRENT)
OUTPUT RESISTANCE

FIGURE 19. BRIDGE PERFORMANCE

The bridge curves are for a ±(0.05% + 1 dial division) unbalance. The solid curves are for a 10-volt generator; the dotted curves represent the bridge performance with a 300-volt supply. Measurements to 1 megohm are with a resistance circuit. From 1 megohm to 100,000 megohms a conductance circuit is used. This bridge has a light-beam galvanometer. Three different meter damping conditions are provided. Optimum damping is obtained by placing a resistance in series with the detector when the supply source has a low resistance, connecting directly to the meter when the source has the proper damping resistance and placing a resistance in parallel when the source has a high resistance. There are three sensitivity conditions and these, combined with the three damping conditions, result in nine combinations of detector performance. The resulting curves for 1/5 scale division on the galvanometer are drawn only for the ranges for which they are applicable. The optimum detector control settings and the measurement sensitivity can be determined from the curves.

For example, measuring a 10-ohm resistor using the 10-ohm to 100-ohm range with the damping switch in position 1 about 15 times as much voltage will be available as is needed for a 0.2 scale division deflection. By changing to damping position 2 some 40 times as much voltage will be available as is needed for 0.2 scale divisions, but the meter will be very sluggish. The center sensitivity position would yield only about 70% of the 0.2 scale division for a 0.05% unbalance. It would require about 0.07% unbalance to yield 0.2 scale division.

CONCLUSION

A bridge-performance analysis technique has been presented. Separate curves of bridge output and detector capability give a visual concept of bridge performance. The technique is useful for analyzing bridge circuits, for comparing detectors, and it can even be extended to such distant fields as plotting speed-torque curves for motors and flux-ampere turn curves for magnets.

REFERENCE

(1) F. Wenner, J. Res. N.B.S., Vol. 25, August 1940. Reprinted in N. B.S. Handbook 77, Vol. 1, Feb. 1, 1961.

esi® Engineering Bulletin

GENERAL

no. 26

Electro Scientific Industries

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AUGUST 1964

REPLACES APRIL 1963

INTERNATIONAL SYSTEM OF UNITS

Quantity	*Unit*	*Symbol*	
	Elemental units		
Length	meter	m	
Mass	kilogram	kg	
Time	second	s	
Electric current	ampere	A	
Temperature	degree Kelvin	°K	
Luminous intensity	candela	cd	
	Supplementary Units		
Plane angle	radian	rad	
Solid angle	steradian	sr	
	Derived Units		
Area	square meter	m^2	
Volume	cubic meter	m^3	
Frequency	hertz	Hz	(s^{-1})
Density	kilogram per cubic meter	kg/m^3	
Velocity	meter per second	m/s	
Angular velocity	radian per second	rad/s	
Acceleration	meter per second squared	m/s^2	
Angular acceleration	radian per second squared	rad/s^2	
Force	newton	N	$(kg \cdot m/s^2)$
Pressure	newton per sq meter	N/m^2	
Kinematic viscosity	sq meter per second	m^2/s	
Dynamic viscosity	newton-second per sq meter	$N \cdot s/m^2$	
Work, energy, quantity of heat	joule	J	$(N \cdot m)$
Power	watt	W	(J/s)
Electric charge	coulomb	C	$(A \cdot s)$
Voltage, potential difference, electromotive force	volt	V	(W/A)
Electric field strength	volt per meter	V/m	
Electric resistance	ohm	Ω	(V/A)
Electric capacitance	farad	F	$(A \cdot s/V)$
Magnetic flux	weber	Wb	$(V \cdot s)$
Inductance	henry	H	$(V \cdot s/A)$
Magnetic flux density	tesla	T	(Wb/m^2)
Magnetic field strength	ampere per meter	A/m	
Magnetomotive force	ampere	A	
Luminous flux	lumen	lm	$(cd \cdot sr)$
Luminance	candela per sq meter	cd/m^2	
Illumination	lux	lx	(lm/m^2)

NBS Technical News Bulletin

April 1964

LITHO IN U.S.A.

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TO FACILITATE the exchange of scientific data, the Bureau has adopted the International System of Units for use by its staff. Henceforth the Bureau will employ this system of units in all its publications except where use of these units would obviously impair communication or would reduce the usefulness of a report to the primary recipients. Standards and measuring devices whose nominal values are in customary U.S. units, like inches, pounds, and gallons, will continue to be calibrated in terms of those units.

The International System of Units (designated SI, for *Systeme International d'Unités*) was defined and given official status in a resolution of the 11th General Conference on Weights and Measures which met in Paris in October 1960.[1] The SI is based on the elemental units. Of these units, those for mass, length, time, and temperature are independent; that is, a definition of one does not depend on definitions of the others. However, the ampere and the candela involve other units in their definitions.

In the International System there is one and only one unit for each quantity, although multiples and submultiples of each unit may be designated by the prefixes approved by the 11th General Conference on Weights and Measures.

[1] Actions of the 11th General Conference on Weights and Measures, *NBS Tech. News Bull.* **44**, *199 (1960)*.

SI PREFIXES

Multiples and Submultiples	*Prefixes*	*Symbols*	*Pronunciations*
10^{12}	tera	T	tĕr′ȧ
10^{9}	giga	G	jĭ′ gȧ
10^{6}	mega	M	mĕg′ȧ
10^{3}	kilo	k	kĭl′ō
10^{2}	hecto	h	hĕk′tō
10	deka	da	dĕk′ȧ
10^{-1}	deci	d	dĕs′ĭ
10^{-2}	centi	c	sĕn′tĭ
10^{-3}	milli	m	mĭl′ ĭ
10^{-6}	micro	μ	mī′ krō
10^{-9}	nano	n	năn′ō
10^{-12}	pico	p	pē′ cō
10^{-15}	femto	f	fĕm′ tō
10^{-18}	atto	a	ăt′ tō

CONVENIENT AUDIO FREQUENCY UNITS

For measurement and calculation in the audio frequency range the conventional electrical units are often inconvenient. A consistent set of units can be chosen so that the numerical values commonly encountered will be more practical while at the same time the equations used in calculations will not require any troublesome conversion constants. If either set of units listed below is followed consistently, the equations used for calculations will be unaltered. For example, $E = IR$ holds true equally well with E in volts, I in amperes, and R in ohms; or with E in volts, I in milliamperes and R in kilohms.

FUNCTION	CONVENTIONAL UNITS	CONVENIENT AUDIO FREQUENCY UNITS
ω	radian/s = $2\pi f_{Hz}$	kiloradian/s = $2\pi f_{kHz}$
f	hertz	kilohertz
t	second	millisecond
C	farad	microfarad
Z, R and X	ohm	kilohm
L	henry	henry
I	ampere	milliamp
E	volt	volt
P	watt	milliwatt
Q and D	per unit ratio	per unit ratio

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